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ENGINEERING TEST AND EVALUATION DURING HIGH G

Volume III: Anti-G Suits

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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In this final volume of a three-volume study report, a protocol for testing anti-G suits is described and the test results from 6 test items are reported. These items are: 3 inservice units from USAF and USN; an RAF unit; and 2 experimental units (lower body full pressure, and capstan). The study of the capstan suit is extended to investigate the man-suit interface. Field-test protocols for anti-G suits and anti-G valves are also proposed.

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S U M M A R Y

At the USAF School of Aerospace Medicine (USAFSAM), the Biodynamics Branch (VNB) has the responsibility of developing, testing, prototyping, evaluating, and recommending all methods of improving G tolerance in aircrew members flying fighter attack aircraft. The VNB physiologic studies use various sustained G levels; and human subjects are tested during simulated aerial combat maneuvers, under repetitive G, or under other G exposures that may become part of the Air Force mission (e.g., space-shuttle launch and reentry studies). Hence the general objective of the "Engineering Test and Evaluation During High G" (TEHG) program, for which Technology Incorporated served as contractor, has been to provide engineering data in support of the USAFSAM/VNB mission.

All work was performed in the VNB Human Centrifuge Facility. The three resulting volumes, plus appendixes, then underwent the necessary revision and editing by the USAFSAM Medical Editing Section.

Volume I, Data Evaluation Techniques and Equipment Tests, SAM-TR-78-10, summarizes the TEHG program and provides information on data acquisition systems, mathematics and data analysis, and specific equipment evaluation.

Volume II, Anti-G Valves, SAM-TR-78-11, affords detailed descriptions of the anti-G valve test protocol, definition of curves, specific anti-G valve evaluations, and standardized anti-G valve test protocol.

Volume III, Anti-G Suits, SAM-TR-78-12, also affords detailed descriptions of the anti-G suit test protocol, definition of curves, and specific anti-G suit evaluations, as well as anti-G protective system field-test procedures and supplemental pneumatic lever anti-G suit evaluation.

The Appendixes, because of their size, could not be included in any of the TEHG volumes. However, microfiche copies of all of the Appendixes (A - R) are available through: The Strughold Aeromedical Library, Documentation Section, Brooks AFB, Texas 78235.

PREFACE

As Project Scientist of Contract F41609-75-C-0026, I would like to acknowledge Ms. Ena Borden Shaw (of our Medical Editing Branch) for the outstanding manner in which she critically, and expertly edited this technical report. It was a very time-consuming project--requiring technical skills and dedication, on the part of Ms. Shaw, that enabled the USAF School of Aerospace Medicine and Technology Incorporated to produce such a useful document.

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ENGINEERING TEST AND EVALUATION DURING HIGH G

VOLUME III:

ANTI-G SUITS

1. ANTI-G SUIT OPERATION AND MONITORING PRINCIPLES

The physiologic effects of acceleration are already well documented. In brief, when acceleration of sufficient magnitude is applied to the body from head to foot (G_z), the blood drains from the upper body (or, at least, this G_z inhibits the arrival of freshly oxygenated blood) and then pools in the lower abdomen and legs. The resulting oxygen hypoxia produces not only reductions in visual acuity and in field of view but, eventually, unconsciousness. Many of the common maneuvers of high-performance aircraft produce just such effects upon pilots and other crew members. Fortunately, modern high-performance aircraft are equipped with an anti-G protective system to reduce these adverse physiologic effects on aircrew members by increasing their individual G_z tolerance. The anti-G protective system comprises two major subsystems--the anti-G valve, and the anti-G suit. (The primary function of the anti-G valve, already described in Vol. II, section 1, is to provide pressure to the anti-G suit at a prescribed schedule of psig/G_z.)

The anti-G suit is an outer garment, usually worn over a flight suit or undergarment, and usually covers the abdominal area and legs like a pair of pants. The suit raises G tolerance by restricting blood flow to the lower body during high G_z, thus reducing the loss of blood from the brain. Anti-G suits vary in design and detail, but are of two basic types: the pneumatic bladder suit, and the pneumatic lever (Capstan) suit.

1.1 Pneumatic Bladder Anti-G Suit

The pneumatic bladder anti-G suit is constructed with a series of interconnected bladders which are usually on the abdomen, thighs, and calves. These bladders are so located between the outer covering of the anti-G suit and the wearer that, as the bladders are pressurized, they expand against the body and restrict the flow of blood.

EDITOR'S NOTE: The Appendixes (A - R) concern the entire TEHG series, rather than any one volume. Hence, all of these Appendixes apply to, and supplement, Volumes I, II, and III. (Information on how to order all, or part, of these Appendixes appears at the close of each volume.)

1.2 Pneumatic Lever Anti-G (Capstan) Suit

The pneumatic lever anti-G suit (or Capstan suit) is constructed with relatively close-fitting legs which are connected to an inflatable tube by interdigitized tapes down the outside of each leg. As the tubes are pressurized, they expand, pulling the fabric tighter about the legs and thus restricting the flow of blood. Each pneumatic lever suit is usually fitted with a separate pneumatic bladder over the abdomen.

1.3 Criteria and Objectives of the Anti-G Suit Tests

Anti-G suits were tested for operation in several areas, both in a static and in a high G_z environment. The suits were tested to establish, respectively: (1) their internal volume at a range of pressures from 0 psig to their rated maximum pressure; (2) their internal flow capability, to ascertain their ability to follow a rapidly changing pressure schedule; (3) the relative uniformity and hysteresis of force between the various bladders and the surface of a mannequin; and (4) the effect, using the human centrifuge, of a high G_z environment on performance.

The objective of the anti-G-suit test protocol was a uniform approach for investigating, by testing and data analysis, the performance characteristics of anti-G suits. Because of the various design approaches and specifications represented by the suits, no attempt was made to present a protocol specifically applicable to all suits, nor to quantify the parameters measured. Quantification of the tests was dictated through two processes: first, by mutual agreement between pertinent staff members of the Crew Technology Division (VNB) and of the Biometrics Division (BRP), in the USAF School of Aerospace Medicine (USAFSAM), and of Technology Incorporated; and second, by the test results which indicated areas of operation requiring more investigation.

2. ANTI-G SUIT TEST PROTOCOL

Six types of anti-G suits were tested under the new protocol during the "Engineering Test and Evaluation During High G" (TEHG) Program. All tests were conducted at the USAFSAM/VNB laboratories at Brooks Air Force Base. The protocol was divided into three phases. The first two phases dealt with the static and operational characteristics of the suit, and the third investigated the effects of the applied G field on the suits' operational characteristics. All dynamic data were recorded on magnetic tape, digitized, and processed through the computational facilities of USAFSAM/BRP. (Refer to Vol. I, section 3, for detailed explanations of the data analysis techniques.)

2.1 Test Configuration

Two basic test configurations were used for evaluating anti-G suits: The first (Fig. 1) was used for the suit volume and stretch tests (refer to section 2.3 - Phase I); the second (Fig. 2), for dynamic response and G-sensitivity testing (refer to section 2.3, Phases II and III).

For both configurations, source pressure was provided by standard "K bottles" of water-pumped compressed air containing up to 220 SCF at 220 psig. This source was controlled by a spring diaphragm pressure regulator, manually adjustable for a secondary pressure between 0 psig and 300 psig.

2.1.1 Suit-Volume Configuration

In the suit-volume configuration (Fig. 1), all pressures and flows were manually regulated by means of needle valves; and all data were manually recorded. The known volume was made up of available portable oxygen cylinders, as required to accommodate the volume of the suit under test.

2.1.2 Suit-Response Test Configuration

In the suit-response test configuration, the source pressure was automatically controlled by a solenoid valve. This valve was driven by a custom-made electronic controller which responded to the output of the suit-pressure transducer.

EDITOR'S NOTE: Available, on p. 151, is a selective list (plus definitions) of the "Abbreviations, Acronyms, and Symbols" used throughout this volume.

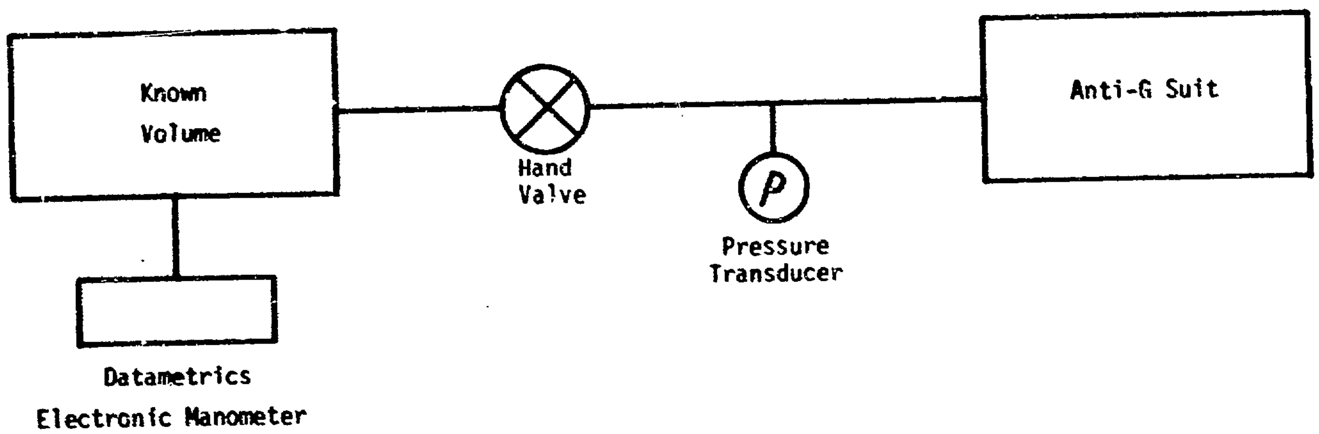

Figure 1. Configuration for conducting volume and stretch tests of anti-G suits.

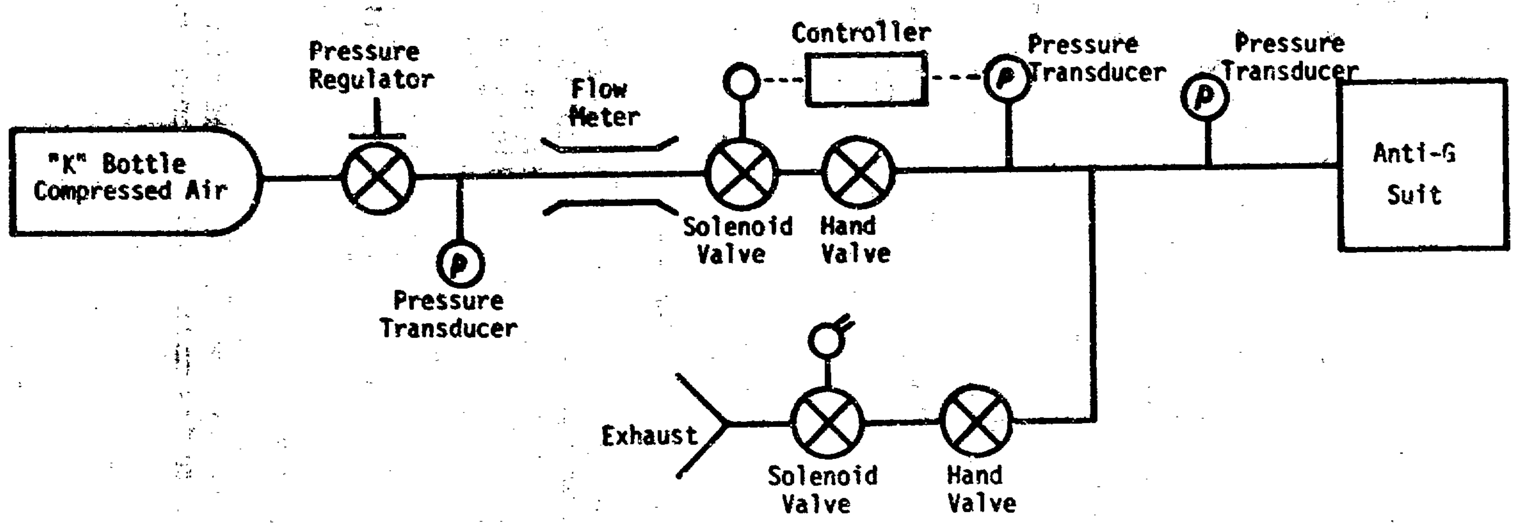

Figure 2. Configuration for conducting dynamic response and G-sensitivity tests of anti-G suits.

The electronic controller opened the source solenoid valve in response to a manual start switch (remote) command. When the suit pressure reached a predefined pressure (manually selected in the controller), the source solenoid was automatically shut off.

The suit fill rate was manually (and empirically) set by using a needle valve located downstream from the control solenoid. This valve served as the principal pressure-reduction port, and was capable of passing up to 40 SCFM (with a high side pressure of 300 psig). This valve, in combination with the pressure regulator, was used to vary the suit fill time.

The suit exhaust was manually controlled through a solenoid valve and a gate valve. All exhaust plumbing to the suit connector was a minimum of 1-1/4 in. (3.18 cm) o.d. pipe to assure negligible line-pressure drop. Exhaust times were empirically adjusted to match the pressurization time (refer to section 2.3.2).

A relief valve was installed in the main pressure line, just upstream from the suit connection. This valve (Jayco Model 312) was set for approximately 11 psig and was capable of passing 60 SCFM.

The anti-G suit under test was fitted to a fiberglass mannequin, oriented to simulate a pilot sitting in an aircraft seat, with both feet on the rudder pedals.

2.2 Parameters Monitored

2.2.1 Source Pressure (P_S)

A source pressure transducer was located immediately downstream from the known volume in the suit-volume test configuration, and immediately upstream from the flow transducer in the suit-response test configuration. In both cases, the in-line pressure port was designed and positioned to minimize errors due to supply line pressure drops and venturi effects. During the suit-volume tests, the Datametrics pressure calibration system was used to monitor this parameter. A Taber Teledyne (Type 176) 0-500 psig transducer was used for the suit-response tests.

2.2.2 Suit Pressure (P_V)

A suit-pressure transducer was positioned immediately upstream from the inlet to the anti-G suit in both test configurations,

and monitored pressure at this point. The transducer port was so placed to minimize errors due to pressure drop, through interconnecting tubing, and due to venturi effects. A Giannini Model 451212-4 (0-30 psia) transducer was used in the suit-volume test configuration. In the suit-response test configuration, a Statham Model P6TC-20D-400 (±20 psid) transducer was used.

2.2.3 Air Flow (F_v)

A Datametrics mass flow transducer Model 1000-2, positioned immediately downstream from the source pressure transducer port, was used to monitor air flow. This transducer has an effective range of 0.6 to 60 SCFM.

2.2.4 Acceleration (G_z)

The Z-axis (i.e., perpendicular to the floor of the gondola) was monitored by the accelerometer (Page Engineering Model CA19R-20G-1311) presently being used for most investigations on the USAFSAM human centrifuge.

2.2.5 Suit Volume (V_s)

The volume of the anti-G suit under test was adjusted by changing the "fit" of the suit on the mannequin. The volume was measured by evacuating the suit with a mild vacuum and then pressurizing the suit to the specified pressure from a known volume (refer to section 2.1.1).

2.2.6 Anti-G Suit Bladder Pressure (P_b)

The relative pressure, in five individual pressure bladders of the anti-G suit, was continuously monitored by "force buttons" (i.e., strain gages mounted inside a disk and designed to measure forces normal to the face of the disk) mounted on the abdomen, both thighs, and both calves of the test mannequin. The force buttons (Houston Scientific Model 1200-015) were designed by the manufacturer to operate from 0 to 15 psi [terminology used by manufacturer].

2.2.7 Signal Conditioning and Recording

Most of the data recorded for these tests utilized the standard techniques for the majority of tests run on the USAFSAM human

centrifuge. These techniques involved passing the electrical signals through slip rings to the control console, amplifying or attenuating as necessary, and recording the most important of the processed signals on the control console Brush recorder. In addition, data collection included filtering and rescaling the signals in the Data Center, recording the reprocessed signals on magnetic tape, and re-recording the output of the tape recorder playback electronics on one or two Brush recorders in the Data Center, adjacent to the SAM Human Centrifuge Control Room.

Selected parameters were monitored on expanded scales to provide improved resolution. This technique involves paralleling the raw data signal into two signal-conditioning amplifiers. One amplifier is scaled to monitor the full range of the output signal, and serves as a baseline standard for the second amplifier. The gain of the second amplifier is set and calibrated at 5 to 20 times the "standard amp" and the direct current (dc) offset capability used to "chase" the signal to the value of interest. The resulting signal is used to study small variations in relatively large signals (especially where dead band and hysteresis are of interest), while the "standard amp" serves as a true parameter value monitor.

2.3 Test Description

The performance evaluation tests for anti-G suits were conducted in the following phases (I - III). In some cases, the design of a particular suit or the resulting data dictated the addition or deletion of all, or part, of a phase.

2.3.1 Phase I--Suit Volume and Stretch Test

The purpose of this test was to determine the operationally probable variations in suit volume with respect to size (if available) and bladder pressure.

A) A full range of suit sizes (as available) were tested for "unmounted" volume (i.e., not fitted to a man or mannequin). Where possible, at least one suit of the proper size was tested on a subject and on a mannequin, under the following conditions (configurations):

1) a proper fit, on a man;

2) a proper fit, on a mannequin;

3) the loosest practical fit, on a mannequin; and

4) the tightest possible fit, on a mannequin.

From these data, the operationally probable size variations was estimated. All volumes calculated under this paragraph resulted from a standard 5-psig internal bladder pressure.

B) One suit was properly fitted on a mannequin; and the volume was determined for at least 12 pressures, distributed between 0 psig and the design maximum pressure, with a data point concentration around 0 psig (e.g., 0, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 psig).

[NOTE: If a mild vacuum is applied to the suit, a finite volume of air, perhaps an appreciable volume, will be required before the pressure in the suit will start to rise.]

Volumes for Phase I were calculated: as "incompressible" volumes (i.e., the volume of incompressible fluid that would be required to fill the suit to the test pressure); and as standard air volumes [SAV] (i.e., the amount of air at ambient pressure required to fill the suit to the test pressure).

2.3.2 Phase II--Suit Response Test

The purpose of this test was to determine the response of the suit to input pressure and flow under static (i.e., 1 G) conditions (test setup in Fig. 2).

A) The fill and exhaust rates were empirically adjusted (and flow rates recorded) to five discrete values, ranging between 1 sec (or the maximum flow handling capability of the test setup) and 20 sec elapsed time between 0 psig and design maximum pressure. The elapsed times, graphically determined by using a semilog scale, were "nearest second (time) approximations" of a 1-2-5-10-20 progression. The maximum inflation and minimum deflation rates were determined, using the maximum suit volume to assure compatibility of the rate schedule between volumes.

B) Data were recorded from five iterations (reduced to three when the quality of the data would allow it) of each fill and exhaust rate for the median suit volume, and at the minimum and maximum fill and exhaust rates for each of the minimum and maximum suit volumes. A complete set of data was taken for the minimum, median, and maximum (operationally probable) suit volumes determined in Phase I.

C) One additional set of inflation iterations was recorded for each suit volume at the standard inflation rate most nearly approximating 1-sec elapsed time and with a mild vacuum applied to the suit immediately before each run. All other inflation iterations were run starting with the suit at ambient pressure.

D) When the span between the elapsed test times for the maximum and minimum flow rates was less than 10 sec, the number of inflation and/or deflation rates tested were reduced by one.

2.3.3 Phase III--G_z Influence Test

The purpose of this test was to determine the influence of an acceleration field on the response of the test item. The same test setup and conditions were used as in Phase II.

Data from five iterations (reduced to three when the quality of the data permitted) of inflation and deflation at the maximum and minimum rates were recorded for each suit volume in stable mean acceleration fields of 2 G and 10 G.

3. DEFINITION OF CURVES (Consult Appendixes H - M.2)

Several standard plots were generated from the G-suit data to aid in the evaluation of suit performance. Each standard set of plots (for a given set of data) is accompanied by a legend. The legend contains curve label definitions, variable range, and maximum deviation in the data from the curve, as appropriate.

Included in Appendixes H - M.2 are the standard graphs and the special comparison graphs, prefaced by descriptions of the respective types. For the convenience of the reader, these descriptions are numbered sequentially from 3.1 to 3.6.6.

4. SPECIFIC ANTI-G SUIT EVALUATIONS

4.1 The CSU-12/P Anti-G Suit

The CSU-12/P is a standard pneumatic bladder type of anti-G suit. The suit is available in six sizes. The bladder casings are made of chloroprene-coated nylon, and the outer cover is made of interwoven nylon and cotton. Bladders are located at the abdomen, right and left thigh, and right and left calf. Suit adjustment is made at the waist, thighs, and calves by means of lacing which is covered by a velcro flap. The suit is connected to the pressure source, through a relatively stiff hose, by a standard breakaway quick-disconnect fitting. This fitting is equipped with a check valve which bleeds suit pressure down to 1.5 psig when disconnected in the pressurized condition.

In reviewing the data presented in section 4 of this volume (and in Appendix H), the following points should be noted:

1) Flow requirements and suit volumes cannot be compared with the suit-volume data, as the test conditions are not the same. The volume tests were made using evacuated suits, while the fill and exhaust tests were made using suits filled to atmospheric pressure.

2) The 2-sec fill rate was used for valve flow delivery requirements to the suit--representing approximately a 4 G/sec G-onset rate.

3) Flow data curves (1- and 2-sec fill rates) generally show a fill time of 1/4- to 1/2-sec longer than the stated fill time. This difference is a result of modeling techniques and data discontinuities, and also of a statistical variation in flow control valve setting.

4.1.1 Suit-Volume Tests

Listed in Table 1 are the volumes (in liters) of the large-long CSU-12/P, and of several configurations of the medium-regular size. The mean values of the volume and the three standard deviations are based on a sample of three runs for each suit size. The volumes were calculated at a suit pressure of 5 psig. In Figure 3, the same data are shown as points on the 5-psig ordinate. The mean volume for an unmounted CSU-12/P suit is 13.307 liters.

The various configurations of the medium regular size were obtained by adjusting the suit on a fiberglass mannequin to be: looser than normal; tighter than normal; and normal. The suit was also tested while properly fitted to a human subject. These volumes were used to establish an average volume for the later tests.

Listed in Table 2 is the "stretch" volume of a CSU-12/P medium regular suit mounted on a fiberglass mannequin. These data (Fig. 3) were obtained by evacuating the suit with a mild vacuum, then raising the suit pressure in 1-psig steps, and calculating the suit volume at each step. Three standard deviations from the mean are also shown.

It should be noted that the indicated suit volume increases rapidly until a pressure of about 1 psig is attained. This increase is primarily due to the volume of air required to "fill out" the suit from the evacuated condition. From 1 to 10 psig, the suit volume increases in a reasonably linear fashion at a rate of approximately 0.30 liter/psig.

Tables 3 and 4, and Figure 4, show the same data as Tables 1 and 2, and Figure 3, except that anti-G suit volumes are expressed in terms of standard air volumes (SAV); i.e., the volume, in liters, occupied by the air in the suit at 14.7 psia. This information is useful in calculating suit leak flow.

4.1.2 Flow Impedance

The CSU-12/P filled to required pressures at the experimental fill rates, except at the 1-sec fill rate. The fill hose impedance of this suit was quite high and prevented suit pressure from reaching the required 10 psig in 1 sec for any of the suit configurations.

AUTHOR'S NOTE: For expanded information on the data summarized in section 4, consult Appendix H: "CSU-12/P Anti-G Suit Data Curves." Therein, each set of curves is preceded by a table containing the minimum and maximum suit pressure, force gage readings, and flow readings, and representative deviations from the mean of the data. While absolute maximum and minimum force gage readings and suit-pressure readings are presented in table form, the actual curves are normalized curves. Relative comparisons are necessary, since absolute force gage readings are a function of variables other than suit pressure and fill rate. Other variables include: area of suit contact with the force gage; bladder form; and suit fit.

TABLE 1. VOLUMES OF THE CSU-12/P ANTI-G SUIT

SUIT SIZE	CONFIGURATION	VOLUMES (liters)			$\bar{V}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]		
Large-Long	Unmounted	13.551	13.530	13.462	13.514	0.140
Medium-Regular	Unmounted	13.139	13.085	13.077	13.100	0.101
Medium-Regular	Mannequin: Loose fit	10.086	10.048	10.169	10.101	0.186
Medium-Regular	Mannequin: Proper fit	7.787	7.837	7.783	7.802	0.090
Medium-Regular	Mannequin: Tight fit	7.383	7.446	7.369	7.399	0.123
Medium-Regular	Subject: Proper fit	10.211	10.305	10.388	10.301	0.266

TABLE 2. STRETCH VOLUMES OF THE CSU-12/P ANTI-G SUIT
(MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_V (psig)	SUIT STRETCH VOLUMES (liters)			$\overline{V}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]		
0+	5.219*	4.900	4.812	4.856	0.187
0.5	8.132	8.407	8.338	8.292	0.429
1.0	8.612	8.849	8.887	8.783	0.447
2.0	9.217	9.363	9.491	9.357	0.411
3.0	9.605	9.751	9.865	9.741	0.391
4.0	9.925	10.098	10.161	10.061	0.367
5.0	10.237	10.404	10.470	10.370	0.360
6.0	10.483	10.684	10.710	10.626	0.373
7.0	10.784	10.910	10.965	10.886	0.278
8.0	11.056	11.239	11.194	11.163	0.286
9.0	11.350	11.460	11.459	11.423	0.190
10.0	11.564	11.700	11.707	11.657	0.241

*Supplemental data indicate that this datum is in error and is discarded when calculating $\overline{V}$ and 3σ.

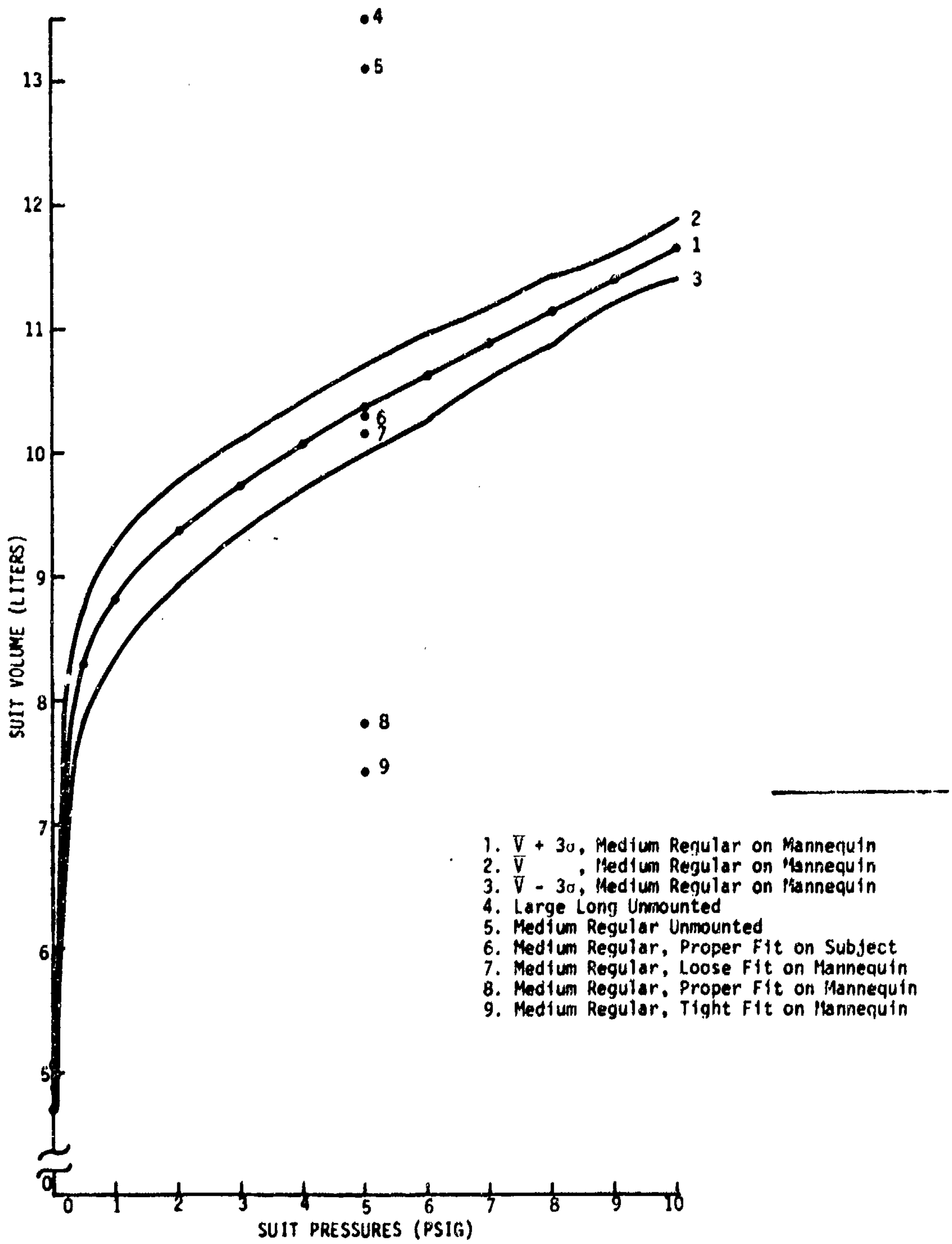

Figure 3. Volume of the CSU-12/P anti-G suit.

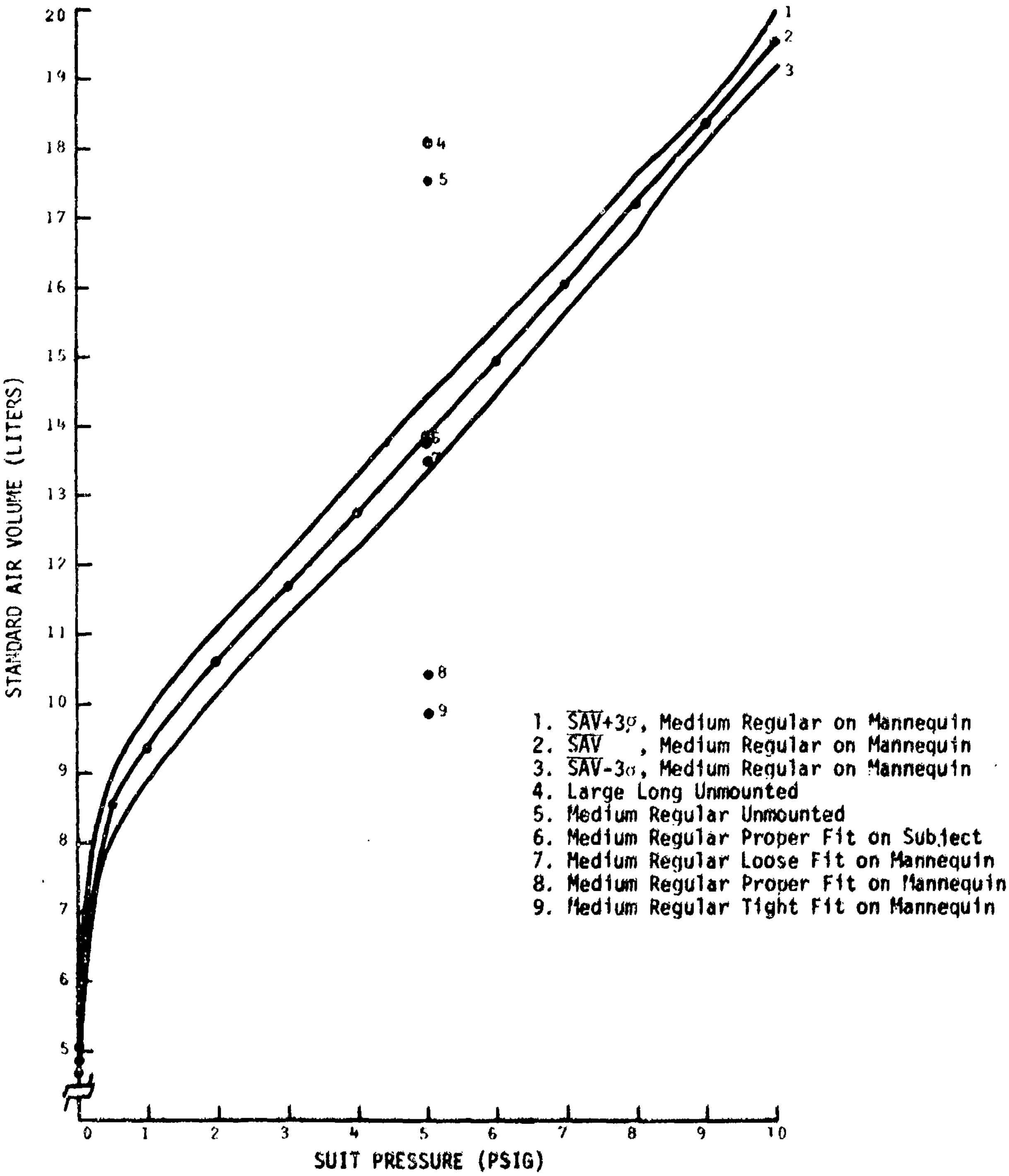

Figure 4. Standard air volume of the CSU-12/P anti-G suit.

TABLE 3. STANDARD AIR VOLUMES OF THE CSU-12/P ANTI-G SUIT

SUIT SIZE	CONFIGURATION	STANDARD AIR VOLUMES (liters)			$\overline{SAV}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]		
Large-Long	Unmounted	18.103	18.075	18.029	18.069	0.112
Medium-Regular	Unmounted	17.553	17.525	17.470	17.516	0.127
Medium-Regular	Mannequin: Loose fit	13.475	13.424	13.620	13.506	0.305
Medium-Regular	Mannequin: Proper fit	10.396	10.489	10.390	10.425	0.167
Medium-Regular	Mannequin: Tight fit	9.864	9.947	9.844	9.885	0.164
Medium-Regular	Subject: Proper fit	13.666	13.757	13.868	13.764	0.303

TABLE 4. STRETCH STANDARD AIR VOLUMES OF THE CSU-12/P ANTI-G SUIT (MEDIUM-REGULAR, ON MANNEQUIN)

PRESSURE: P_v (psig)	STRETCH STANDARD AIR VOLUMES (liters)			$\overline{SAV}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]		
0+	5.223*	4.903	4.815	4.859	0.187
0.5	8.408	8.720	8.620	8.583	0.478
1.0	9.195	9.448	9.489	9.377	0.478
2.0	10.465	10.631	10.775	10.624	0.465
3.0	11.555	11.731	11.868	11.718	0.471
4.0	12.578	12.831	12.912	12.774	0.523
5.0	13.667	13.925	14.013	13.868	0.539
6.0	14.740	15.023	15.059	14.941	0.524
7.0	15.894	16.079	16.160	16.944	0.409
8.0	17.042	17.324	17.256	17.207	0.441
9.0	18.264	18.441	18.401	18.369	0.278
10.0	19.391	19.618	19.630	19.546	0.404

* Supplemental data indicate that this datum is in error and is discarded when calculating $\overline{SAV}$ and 3σ.

4.1.3 Maximum (Max) Fill Rates

The 1-sec and 20-sec fill rates for the three suit sizes are compared in Table 5:

TABLE 5. FLOW RATES OF THE CSU-12/P ANTI-G SUIT

JIT VOL.	F_M	$\bar{F}_M$	F_M	$\bar{F}_M$
	[1 sec]		[20 sec]	
Min	*48.2	*22.7	30.3	4.2
Mid	*48.3	*23.2	23.0	3.5
Max	*46.0	*24.7	27.3	4.5

F_M = the peak flow measured during the 3 runs.

$\bar{F}_M$ = the average maximum flow.

*See report section 4.1.2.

4.1.4 Flow Requirements

A steady flow of 14 SCFM and a peak flow of 30.3 SCFM were required to fill the CSU-12/P suit in the required 2-sec time interval. Therefore, any valve used with the CSU-12/P should be able to deliver such flow rates for G-onset rates approaching 4 G/sec.

4.1.5 Normalized Parameters

The normalized force gages and suit-pressure profiles are very tight (e.g., grouped) at all fill rates. This finding indicates that the CSU-12/P fills and bleeds as a unit, with all bladders following the input suit pressure.

4.1.6 G-Force Effects

The CSU-12/P was run through identical 1-sec and 20-sec fill and bleed tests under static conditions, 2 G and 10 G. Shown in Tables 6 and 7 is the maximum normalized difference for the respective parameters under G and static conditions. Examination of graphs of the cases resulting in the greatest differences (refer to Appendix H) reveals that these generally occur:

1) at flow shut-off point,

2) during the first ¼ sec of data, or

3) at discontinuities in the curves.

Examination of the following tables, and associated plots, indicates that there is very little G-effect upon the performance of the CSU-12/P. Suit-pressure deviations between static and the 10-G_z condition are as high as 0.95 psig. Corresponding force-button readings do not, however, indicate variations of this magnitude. Since the high deviations are limited to the 1-sec fills, especially the suit-pressure channel, these deviations were probably caused by the hose impedance in this suit. (See Appendix H, p. 74.) All deviations in force gage readings between static and G-stressed conditions, with the exception of the 1-sec fill, are less than 0.1 and are probably not physiologically significant.

4.2 The CSU-13A/P Anti-G Suit

The CSU-13A/P is a standard pneumatic bladder type of anti-G suit. Bladders are located at the abdomen, left and right thigh, and left and right calf. The bladder casing is fabricated of a polyurethane-coated nylon taffeta, and the outer cover is high-temperature resistant cloth (NOMEX). The CSU-13A/P is adjusted by lacings, at the waist and on the left and right thigh. Lacing covers are fastened with velcro tape. The suit is connected through a flexible hose to the pressure source (anti-G valve) by a break-away quick-disconnect fitting. This fitting is equipped with a check valve designed so that, if the suit is disconnected in the pressurized condition, it will bleed down to 1.5 psig in about 3 sec. Suit pressure will continue to bleed down to 0.5 psig in an additional 3 - 5 sec.

Data from Appendix I, "CSU-13A/P Anti-G Suit Data Curves," are presented in the following subsections in summary and table form. Before these data are examined, the following considerations must be noted:

1) Flow requirements and suit volumes cannot be compared with the suit-volume data, as the test conditions are not the same. The volume tests were run using evacuated suits, while the fill and exhaust tests were made using suits filled to atmospheric pressure.

2) The 2-sec fill rate was used for valve flow delivery requirements to the suit--representing approximately a 4 G/sec G-onset rate.

3) Flow data curves (1- and 2-sec fill rates) generally show a fill time of ¼- to ½-sec longer than the stated fill time. This difference is a result of modeling techniques and data discontinuities, and also of a statistical variation in flow control valve settings.

TABLE 6. THE 1-SEC AND 20-SEC FILL-RATE TESTS OF THE CSU-12/P ANTI-G SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
[FILL RATE = 1 SEC; G-FORCE = 2 G_z]						
MIN	0.15155	0.03294	0.02060	0.01466	0.02224	0.02349
MID	0.18003	0.03247	0.03960	0.02961	0.05832	0.07411
MAX	0.85493	0.15534	0.15040	0.23613	0.16676	0.24605
[FILL RATE = 1 SEC; G-FORCE = 10 G_z]						
MIN	0.82945	0.19935	0.21249	0.18331	0.14495	0.20870
MID	0.47515	0.07411	0.08103	0.06534	0.03095	0.06710
MAX	0.94914	0.18504	0.17091	0.29803	0.20988	0.23594
[FILL RATE = 20 SEC; G-FORCE = 2 G_z]						
MIN	0.00405	0.00570	0.00382	0.00401	0.00552	0.00483
MID	0.02595	0.02637	0.02465	0.02926	0.02692	0.02712
MAX	0.09307	0.01277	0.01118	0.00869	0.01168	0.00839
[FILL RATE = 20 SEC; G-FORCE = 10 G_z]						
MIN	0.00779	0.01408	0.00973	0.01051	0.01350	0.00829
MID	0.04002	0.04873	0.04177	0.19587	0.04364	0.03731
MAX	0.01348	0.01530	0.01768	0.01170	0.02520	0.03209

TABLE 7. THE 1-SEC AND 20-SEC EXHAUST RATE TESTS OF THE CSU-12/P ANTI-G SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
		[EXHAUST RATE = 1 SEC; G-FORCE = 2 G_z]				
MIN	0.03366	0.02593	0.01491	0.01424	0.01684	0.01265
MID	0.04563	0.05146	0.01410	0.01760	0.01169	0.01170
MAX	0.04554	0.05271	0.01429	0.00950	0.03317	0.01358
		[EXHAUST RATE = 1 SEC; G-FORCE = 10 G_z]				
MIN	0.05531	0.02868	0.02515	0.03136	0.02683	0.02897
MID	0.11221	0.03745	0.02754	0.01220	0.01883	0.03471
MAX	0.07113	0.04218	0.01879	0.01437	0.03943	0.05124
		[EXHAUST RATE = 1 SEC; G-FORCE = 2 G_z]				
MIN	0.00557	0.01263	0.00707	0.00818	0.01018	0.00949
MID	0.00870	0.01540	0.00559	0.00505	0.00838	0.01061
MAX	0.00504	0.01747	0.00768	0.00996	0.01284	0.00798
		[EXHAUST RATE = 1 SEC; G-FORCE = 10 G_z]				
MIN	0.00874	0.01674	0.01121	0.01480	0.02433	0.01144
MID	0.06431	0.05238	0.04372	0.05659	0.05369	0.07151
MAX	0.00934	0.02094	0.04617	0.00909	0.00875	0.01444

In addition to the curves and the tables included in the following subsections, each set of curves in Appendix I is preceded by a table containing the minimum and maximum suit pressure, force gage readings and flow readings, and representative deviations from the mean of the data.

Lastly, while absolute maximum and minimum force gage readings and suit-pressure readings are presented in table form in Appendix I, the actual curves are normalized curves. Relative comparisons are necessary, since absolute force gage readings are a function of variables other than suit pressure and fill rate. Other variables include area of suit contact with the force gage, bladder form, and suit fit.

4.2.1 Suit-Volume Tests

Listed in Table 8 are the volumes in liters for the various sizes of the CSU-13A/P, and for several configurations of the medium-regular size. The mean values of the volume and the three standard deviations are based on a sample of five runs for each suit size. The volumes were calculated at a suit pressure of 5 psig. The same data are displayed in graphic form in Figure 5 as points on the 5-psig ordinate.

A large variation (about 20%) in unmounted volume, which exists between the various sizes of the CSU-13A/P, would indicate that the bladders in this suit are different for each of the suit sizes. The mean volume for an unmounted CSU-13A/P suit is 14.119 liters.

The various configurations of the medium-regular size were obtained by adjusting the suit on a fiberglass mannequin to a looser than normal fit, a tighter than normal fit, and a normal fit. The suit was also tested while properly fitted to a human subject. These volumes were used to establish an average volume for the later tests. Shown in Table 9 are the "stretch" volumes of a CSU-13A/P medium-regular suit mounted on a fiberglass mannequin.

These data (Fig. 5) were obtained by evacuating the suit with a mild vacuum, then raising the suit pressure in 1-psig steps, and calculating the suit volume at each step. Three standard deviations from the mean, based on a sample of three runs, are also shown.

It should be noted that the indicated suit volume increases rapidly until a pressure of about 1.5 psig is attained. This increase is primarily due to the volume of air required to "fill out" the suit from the evacuated condition. From 1.5 to 10 psig, the suit volume increases in a reasonably linear fashion at a rate of approximately 0.21 liter/psig.

In Tables 10 and 11, and Figure 6, are shown the same data as in Tables 9 and 10, and Figure 5, except that anti-G suit volumes are expressed in terms of standard air volumes (SAV); i.e., the volume, in liters, occupied by the air in the suit at 14.7 psia. This information is useful in calculating suit leak flow.

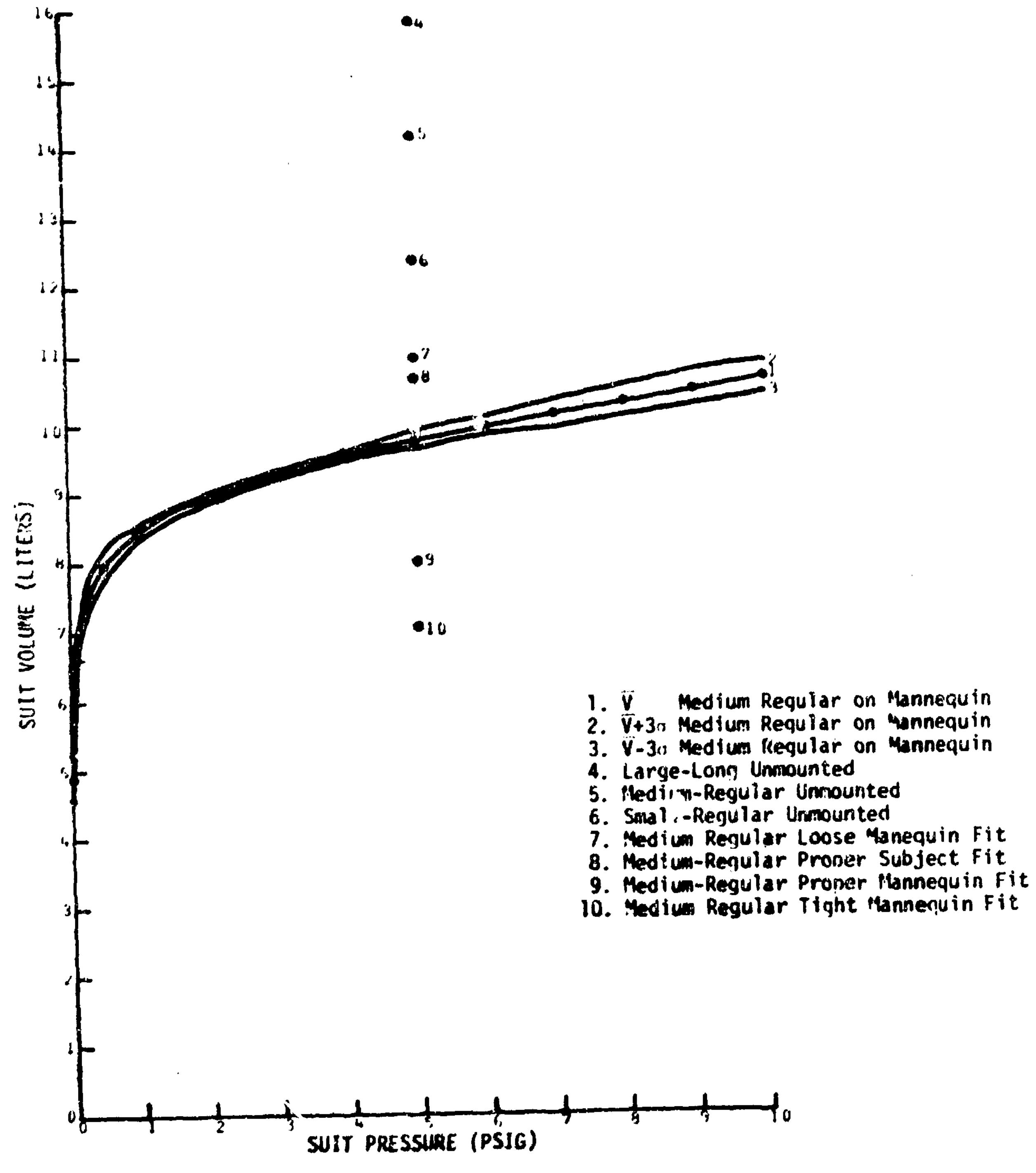

Figure 5. Volumes of the CSU-13A/P anti-G suit.

TABLE 8. VOLUMES OF THE CSU-13A/P ANTI-G SUIT

SUIT SIZE	CONFIGURATION	VOLUMES (liters)					$\bar{V}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Small-Regular	Unmounted	12.345	12.334	12.392	12.299	12.351	12.344	0.100
Large-Long	Unmounted	15.673	15.807	15.884	15.914	15.844	15.824	0.281
Medium-Regular	Unmounted	14.112	14.226	14.123	14.272	14.214	14.189	0.208
Medium-Regular	Mannequin: Loose fit	10.864	10.950	11.004	10.938	11.042	10.960	0.204
Medium-Regular	Mannequin: Proper fit	7.920	7.911	7.932	7.906	7.878	7.909	0.060
Medium-Regular	Mannequin: Tight fit	7.044	7.061	7.113	7.085	7.155	7.092	0.132
Medium-Regular	Subject: Proper fit	10.751	10.717	10.549	10.811	10.642	10.694	0.304

TABLE 9. STRETCH VOLUMES OF THE CSU-13A/P ANTI-G SUIT (MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_v (psig)	SUIT STRETCH VOLUMES (liters)			$\overline{V}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]		
0+	5.753*	4.812	4.946	4.879	0.284
0.5	8.017	7.885	8.014	7.972	0.226
1.0	8.406	8.429	8.440	8.425	0.052
2.0	8.945	8.924	8.982	8.950	0.088
3.0	9.267	9.239	9.285	9.264	0.070
4.0	9.539	9.506	9.545	9.530	0.063
5.0	9.773	9.715	9.793	9.760	0.122
6.0	9.933	9.912	9.994	9.946	0.128
7.0	10.125	10.082	10.203	10.137	0.184
8.0	10.288	10.256	10.388	10.311	0.207
9.0	10.470	10.395	10.570	10.478	0.263
10.0	10.627	10.551	10.749	10.642	0.300

*Supplemental data indicate that this datum is in error and is discarded when calculating $\overline{V}$ and 3σ.

TABLE 10. STANDARD AIR VOLUMES OF THE CSU-13A/P ANTI-G SUIT

SUIT SIZE	CONFIGURATION	STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Small-Regular	Unmounted	16.511	16.496	16.641	16.616	16.395	16.532	0.298
Large-Long	Unmounted	21.068	21.248	21.299	21.392	21.299	21.261	0.360
Medium-Regular	Unmounted	18.827	19.028	18.842	19.008	19.011	18.943	0.299
Medium-Regular	Mannequin: Loose fit	14.528	14.644	14.752	14.590	14.766	14.656	0.308
Medium-Regular	Mannequin: Proper fit	10.625	10.613	10.641	10.606	10.568	10.611	0.082
Medium-Regular	Mannequin: Tight fit	9.420	9.443	9.512	9.475	9.568	9.484	0.176
Medium-Regular	Subject: Proper fit	14.423	14.378	14.153	14.467	14.277	14.340	0.378

TABLE 11. STRETCH STANDARD AIR VOLUMES OF THE CSU-13A/P ANTI-G SUIT (MEDIUM-REGULAR, ON MANNEQUIN)

PRESSURE: P_V (psig)	STRETCH STANDARD AIR VOLUMES (liters)			$\overline{SAV}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]		
0+	5.757*	4.815	4.949	4.882	0.284
0.5	8.292	8.155	8.289	8.245	0.235
1.0	8.982	9.006	9.018	9.002	0.055
2.0	10.171	10.147	10.214	10.177	0.102
3.0	11.173	11.139	11.194	11.169	0.083
4.0	12.155	12.080	12.129	12.121	0.114
5.0	13.089	13.045	13.150	13.095	0.158
6.0	13.985	13.988	14.070	14.014	0.145
7.0	14.984	14.884	15.063	14.977	0.269
8.0	15.929	15.810	16.049	15.929	0.358
9.0	16.929	16.772	17.055	16.919	0.425
10.0	17.912	17.746	18.094	17.917	0.522

*Supplemental data indicate that this datum is in error and is discarded when calculating $\overline{SAV}$ and 3σ.

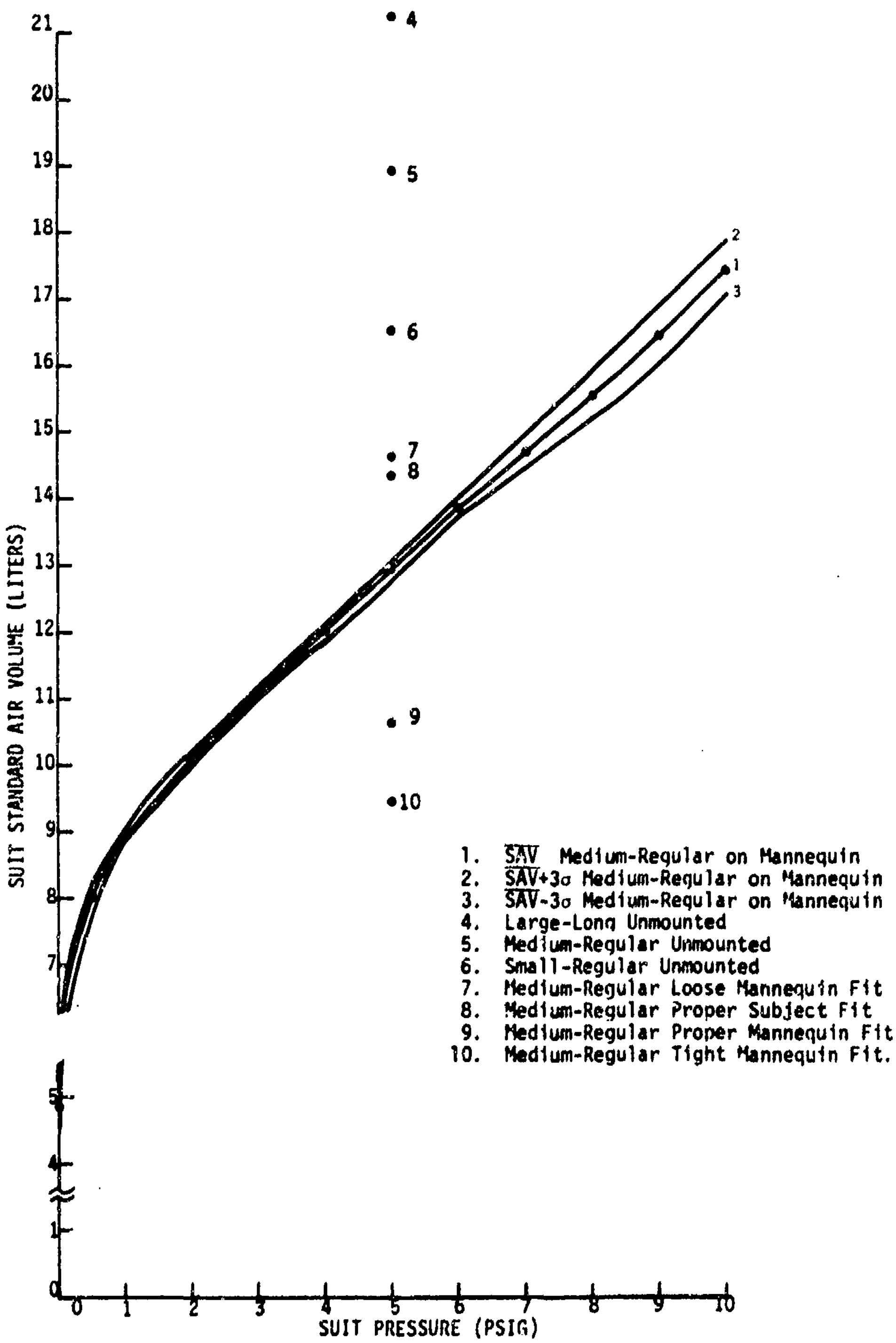

Figure 6. Standard air volumes of the <u>CSU-13A/P</u> anti-G suit.

4.2.2 Flow Impedance

The CSU-13A/P filled to near required pressures at all experimental fill rates.

4.2.3 Maximum (Max) Fill Rates

The 1-sec and 20-sec fill rates for the three suit sizes are compared in Table 12.

TABLE 12. FLOW RATES OF THE CSU-13A/P ANTI-G SUIT

SUIT VOL	F_M	$\bar{F}_M$	F_M	$\bar{F}_M$
	[1 sec]		[20 sec]	
Min	38.3	30.3	13.2	2.0
Mid	39.6	30.5	33.5	4.9
Max	38.7	30.6	33.9	8.0

F_M = the peak flow measured during the 5 runs

$\bar{F}_M$ = the average maximum flow

4.2.4 Flow Requirements

The CSU-13A/P required a steady flow of 18.5 SCFM and a peak flow of 35 SCFM to fill the suit in the required 2-sec time interval. Therefore, any valve used with the CSU-13A/P should be able to deliver these flow rates for G-onset rates approaching 4 G/sec.

4.2.5 Normalized Parameters

The normalized force gage and suit-pressure profiles are very tight (e.g., grouped) at all fill rates. This finding indicates that the CSU-13A/P fills and bleeds as a unit, with all bladders following the input suit pressure.

4.2.6 G-Force Effects

The CSU-13A/P was run through identical 1-sec and 20-sec fill and bleed tests under static conditions, 2 G and 10 G. Tables 13 and 14 contain the maximum normalized difference for the respective parameters

TABLE 13. THE 1-SEC AND 20-SEC FILL-RATE TESTS OF THE CSU-13A/P ANTI-G SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	R' T	LEFT THIGH	RIGHT CALF	LEFT CALF
		[FILL RATE = 1 SEC; G-[illegible] = 2 G_z]				
MIN	0.07698	0.07484	0.07862	0.10198	0.05717	0.09498
MID	0.14787	0.08102	0.10144	0.09895	0.09842	0.09530
MAX	0.12253	0.04799	0.08251	0.02691	0.08480	0.04434
		[FILL RATE = 1 SEC; G-FORCE = 10 G_z]				
MIN	0.11958	0.11693	0.12353	0.16308	0.13816	0.15954
MID	0.08436	0.05426	0.04747	0.05250	0.04871	0.04934
MAX	0.15194	0.07522	0.07382	0.10460	0.07534	0.10956
		[FILL RATE = 20 SEC; G-FORCE = 2 G_z]				
MIN	0.00343	0.00760	0.00563	0.00637	0.00421	0.00444
MID	0.01156	0.05883	0.01778	0.01866	0.02097	0.01626
MAX	0.06275	0.06153	0.05738	0.05938	0.05589	0.05569
		[FILL RATE = 20 SEC; G-FORCE = 10 G_z]				
MIN	0.01270	0.01079	0.01410	0.01366	0.01017	0.01284
MID	0.06391	0.05162	0.01245	0.01934	0.01594	0.02104
MAX	0.03263	0.05297	0.02562	0.01522	0.02141	0.02078

TABLE 14. THE 1-SEC AND 20-SEC EXHAUST RATE TESTS OF THE CSU-13A/P ANTI-G SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
		[EXHAUST RATE = 1 SEC; G-FORCE = 2 G_z]				
MIN	0.02855	0.00896	0.01163	0.02120	0.00709	0.00937
MID	0.03293	0.01349	0.00677	0.00962	0.00611	0.01412
MAX	0.03147	0.01704	0.02275	0.01440	0.00731	0.01038
		[EXHAUST RATE = 1 SEC; G-FORCE = 10 G_z]				
MIN	0.07064	0.01219	0.01946	0.03732	0.01180	0.01292
MID	0.05150	0.00939	0.01880	0.02455	0.01885	0.00679
MAX	0.06448	0.04776	0.03579	0.05493	0.02150	0.02116
		[EXHAUST RATE = 20 SEC; G-FORCE = 2 G_z]				
MIN	0.00499	0.00616	0.00530	0.00593	0.00472	0.00479
MID	0.02671	0.01703	0.00644	0.00651	0.00624	0.00618
MAX	0.09504	0.18087	0.00810	0.09255	0.00550	0.00876
		[EXHAUST RATE = 20 SEC; G-FORCE = 10 G_z]				
MIN	0.01245	0.01913	0.01445	0.01203	0.01732	0.01364
MID	0.04719	0.01484	0.01310	0.01046	0.00568	0.00746
MAX	0.09840	0.20186	0.05233	0.10021	0.02010	0.01756

under G and static conditions. Examination of graphs of the cases resulting in the greatest differences (refer to Appendix I) reveals that these generally occur:

1) at flow shut-off point,

2) during the first ½ sec of data, or

3) at discontinuities in the curves.

Examination of the following tables, and associated plots, indicates that there is no significant G-effect upon the performance of the CSU-13A/P. All deviations between static and G-stressed conditions are less than 0.2 and are probably not physiologically significant. It is significant that, with only two exceptions, all deviations over 0.1 occurred during the 1-sec fill cycle, and are probably the product of suit-skin friction impeding the application or release of pressure on the force sensor.

4.3 CSU-15/P Anti-G Suit

The CSU 15/P High Temperature Resistant Cutaway Anti-G Coverall (Anti-G Suit) was developed and is produced for the U.S. Navy. It is a standard bladder type anti-G suit with five bladders located, respectively, at the abdomen, right and left thigh, and right and left calf. These bladders are interconnected by tubing integral with the suit. The suit is connected to the pressure source (Anti-G Valve) with a standard breakaway quick-disconnect fitting.

This suit differs physically from other similar types by an increased amount of suit adjustment lacing and by a longer flexible suit disconnect hose.

Data from Appendix J: "CSU-15/P Anti-G Suit Data Curves," are presented in the following subsections in summary and table form. Before these data are examined, the following considerations must be noted:

1) Flow requirements and suit volumes cannot be compared with the suit-volume data, as the test conditions are not the same. The volume tests were run with evacuated suits, while the fill and exhaust tests were made using suits filled to atmospheric pressure.

2) The 2-sec fill rate was used for valve flow delivery requirements to the suit--representing approximately a 4 G/sec G-onset rate.

3) Flow data curves (1- and 2-sec fill rates) generally show a fill time of ¼ to ½ sec longer than the stated fill time. This difference is a result of modeling techniques and data discontinuities, and also of a statistical variation in flow control valve settings.

In addition to the curves and the tables in the following subsections, each set of curves in Appendix J is preceded by a table containing the minimum and maximum suit pressure, force gage readings, flow readings, and representative deviations from the mean of the data.

Lastly, while absolute maximum and minimum force gage readings and suit-pressure readings are presented in table form in Appendix J, the actual curves are normalized curves. Relative comparisons are necessary, since absolute force gage readings are a function of variables other than suit pressure and fill rate. Other variables include area of suit contact with the force gage, bladder form, and suit fit.

4.3.1 Suit-Volume Tests

Listed in Table 15 are the volumes (in liters) of the various sizes of the CSU-15/P, and for several configurations of the medium-regular size. The mean values of the volume and the three standard deviations are based on a sample of five runs for each suit size. The volumes were calculated at a suit pressure of 5 psig. The same data are shown in Figure 7 as points on the 5-psig ordinate.

It should be noted that there is not a large variation (about 3%) in unmounted volume between the various sizes of the CSU-15/P. This finding would indicate that the bladders used in this suit are essentially identical for all of the suit sizes. The mean volume for an unmounted CSU-15/P suit is 9.617 liters.

The various configurations of the medium-regular size were obtained by fitting the suit on a fiberglass mannequin to a looser than normal fit, a tighter than normal fit, and a normal fit. The suit was also tested while properly fitted to a human subject. These volumes were used to establish an average volume for the later tests.

Shown in Table 16 is the "stretch" volume of a CSU-15/P medium-regular suit mounted on a fiberglass mannequin.

These data (Fig. 7) were obtained by evacuating the suit with a mild vacuum, raising the suit pressure in 1-psig steps, and calculating the suit volume at each step. Three standard deviations from the mean are also shown.

It should be noted that the indicated suit volume increases rapidly until a pressure of about 2 psig is attained. This increase is primarily due to the volume of air required to "fill out" the suit from the evacuated condition. From 2 to 10 psig, the suit volume increases in a reasonably linear fashion at a rate of approximately 0.175 liter/psig.

In Tables 17 and 18, and Figure 8, the same data are shown as in Tables 15 and 16, and Figure 7, except that anti-G suit volumes are expressed in terms of standard air volume (SAV); i.e., the volume, in liters, occupied by the air in the suit at 14.7 psia. This information is useful in calculating suit leak flow.

TABLE 15. VOLUMES OF THE CSU-15/P ANTI-G SUIT

SUIT SIZE	CONFIGURATION	VOLUMES (liters)					$\overline{V}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Small-Regular	Unmounted	9.513	9.526	9.469	9.496	9.483	9.497	0.068
Large-Regular	Unmounted	9.789	9.824	9.801	9.790	9.805	9.802	0.042
Medium-Regular	Unmounted	9.530	9.541	9.543	9.563	9.587	9.553	0.068
Medium-Regular	Mannequin: Loose fit	8.544	8.638	8.635	8.658	8.641	8.623	0.135
Medium-Regular	Mannequin: Tight fit	5.495	5.561	5.435	5.471	5.486	5.488	0.147
Medium-Regular	Mannequin: Proper fit	6.306	6.303	6.340	6.316	6.331	6.319	0.048
Medium-Regular	Subject: Proper fit	7.713	7.765	7.761	7.700	7.740	7.736	0.086

TABLE 16. STRETCH VOLUMES OF THE CSU-15/P ANTI-G SUIT (MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_v (psig)	SUIT STRETCH VOLUMES (liters)					$\overline{V}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
0+	3.611	3.630	3.835	3.658	3.607	3.678	0.279
0.5	5.318	5.459	---	5.623	5.644	5.511	0.459
1.0	5.781	5.890	5.995	6.001	6.027	5.939	0.308
2.0	6.337	6.382	6.500	6.454	6.494	6.433	0.215
3.0	6.631	6.688	6.765	6.764	6.740	6.718	0.173
4.0	6.858	6.911	6.977	6.945	6.958	6.930	0.140
5.0	7.033	7.098	7.170	7.149	7.139	7.118	0.161
6.0	7.213	7.258	7.311	7.301	7.301	7.277	0.123
7.0	7.363	7.423	7.447	7.426	7.465	7.425	0.115
8.0	7.495	7.552	7.599	7.577	7.567	7.558	0.117
9.0	7.616	7.653	7.730	7.686	7.712	7.679	0.137
10.0	7.754	7.813	7.861	7.862	7.832	7.824	0.133

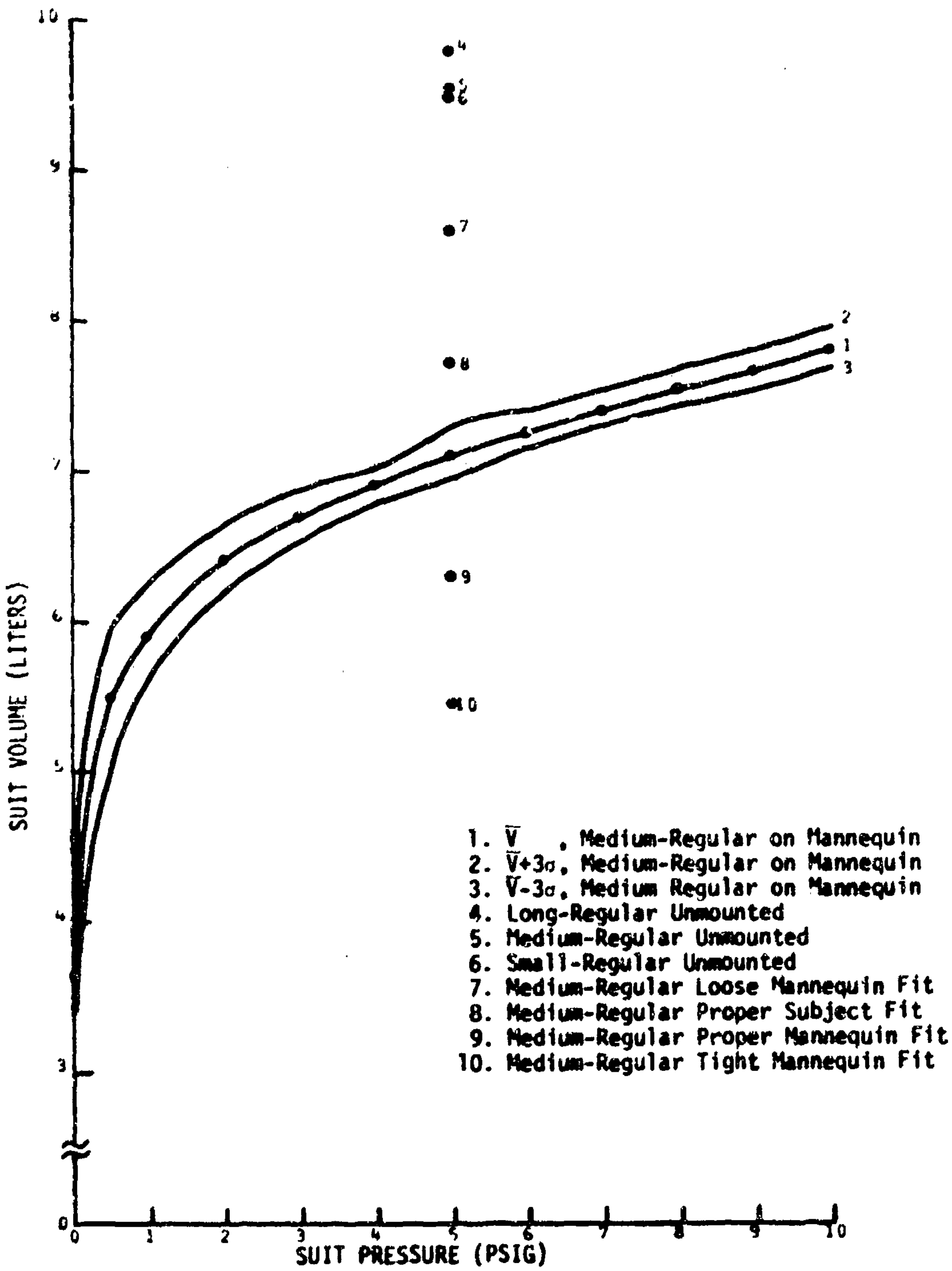

Figure 7. Volumes of the CSU-15/P anti-G suit.

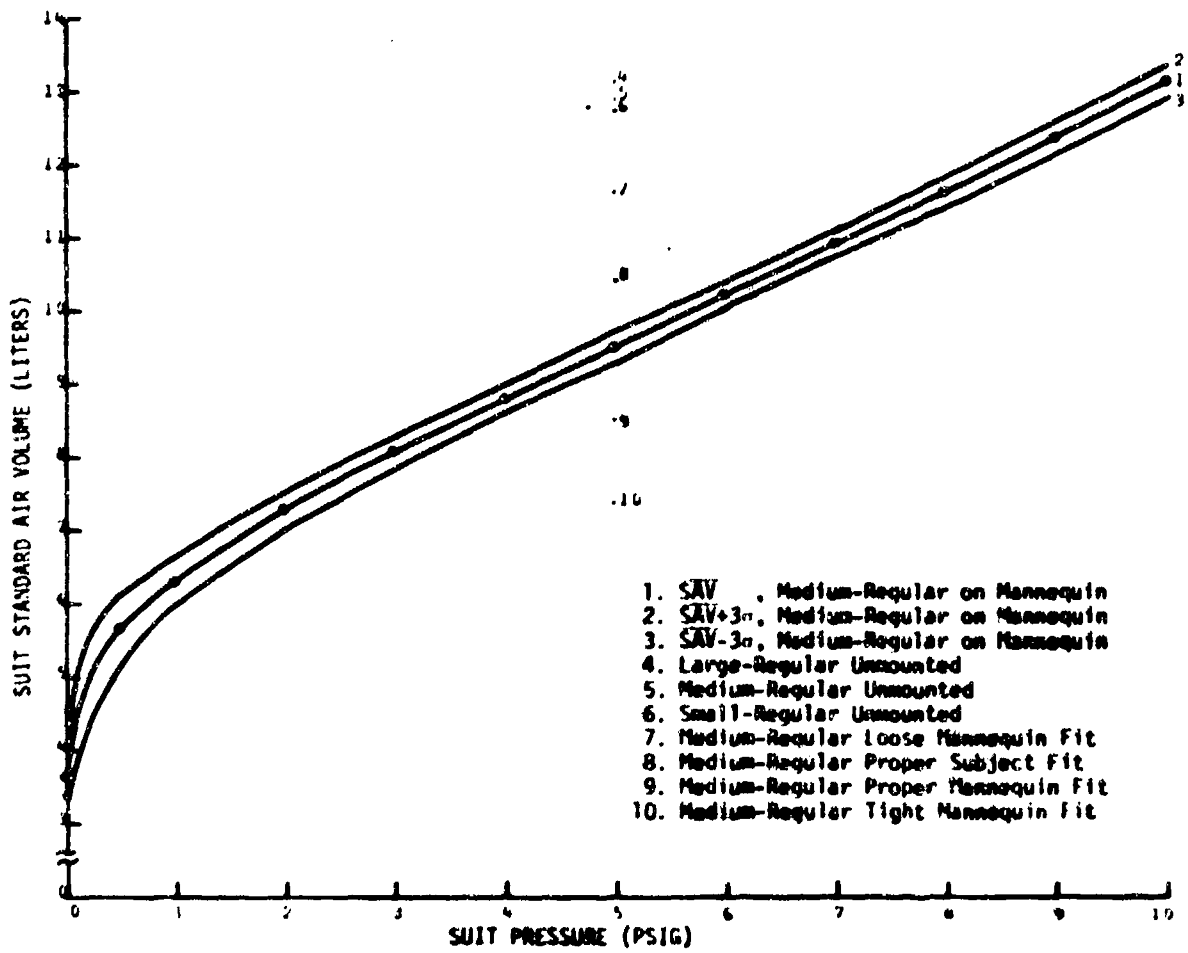

Figure 8. Standard air volumes of the CSU-15/P anti-G suit.

TABLE 17. STANDARD AIR VOLUMES OF THE CSU-15/P ANTI-G SUIT

SUIT SIZE	CONFIGURATION	STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Small-Regular	Unmounted	12.750	12.767	12.659	12.727	12.709	12.722	0.125
Large-Regular	Unmounted	13.119	13.166	13.135	13.121	13.141	13.136	0.057
Medium-Regular	Unmounted	12.773	12.787	12.790	12.817	12.849	12.803	0.090
Medium-Regular	Mannequin: Loose fit	11.568	11.566	11.594	11.442	11.573	11.549	0.182
Medium-Regular	Mannequin: Tight fit	7.359	7.447	7.265	7.327	7.347	7.349	0.197
Medium-Regular	Mannequin: Proper fit	8.445	8.441	8.491	8.459	8.479	8.463	0.065
Medium-Regular	Subject: Proper fit	10.329	10.399	10.393	10.312	10.366	10.360	0.115

TABLE 18. STRETCH STANDARD AIR VOLUMES OF THE CSU-15/P ANTI-G SUIT (MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_V (psig)	STRETCH STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
0+	3.612	3.680	3.835	3.658	3.607	3.678	0.278
0.5	5.499	5.645	---	5.814	5.836	5.698	0.474
1.0	6.175	6.291	6.403	6.410	6.437	6.343	0.328
2.0	7.200	7.251	7.385	7.332	7.378	7.309	0.243
3.0	7.985	8.054	8.147	8.145	8.116	8.089	0.208
4.0	8.725	8.792	8.876	8.835	8.853	8.816	0.179
5.0	9.427	9.514	9.610	9.582	9.569	9.540	0.218
6.0	10.158	10.222	10.297	10.283	10.283	10.244	0.174
7.0	10.871	10.960	10.994	10.965	11.022	10.962	0.171
8.0	11.576	11.664	11.736	11.703	11.687	11.673	0.181
9.0	12.281	12.342	12.465	12.394	12.437	12.387	0.222
10.0	13.031	13.130	13.212	13.213	13.162	13.150	0.223

4.3.2 Flow Impedance

The CSU-15/P filled to near required pressures at all experimental fill rates.

4.3.3 Maximum (Max) Fill Rates

The 1-sec and 20-sec fill rates for the three suit sizes are compared in Table 19.

TABLE 19. FLOW RATES FOR THE CSU-15/P ANTI-G SUIT

SUIT VOL	F_M	$\bar{F}_M$	F_M	$\bar{F}_M$
	[1 sec]		[20 sec]	
Min	24.8	16.2	9.7	1.25
Mid	35.7	26.5	25.4	2.5
Max	43.5	37.4	34.5	5.2

F_M = the peak flow measured during the 5 runs.

$\bar{F}_M$ = the average maximum flow.

4.3.4 Flow Requirements

The CSU-15/P required a steady flow of 13 SCFM and a peak flow of 23 SCFM to fill the suit in the required 2-sec time interval. Therefore, any valve used with the CSU-15/P should be able to deliver these flow rates for G-onset rates approaching 4 G/sec.

4.3.5 Normalized Parameters

The normalized force gage and suit-pressure profiles are very tight (e.g., grouped) at all fill rates. This finding indicates that the CSU-15/P fills and bleeds as a unit, with all bladders following the input suit pressure.

4.3.6 G-Force Effects

The CSU-15/P was run through identical 1-sec and 20-sec fill and bleed tests under static conditions, 2 G and 10 G. Tables 20 and 21 contain the maximum normalized difference for the respective

parameters under G and static conditions. Examination of graphs of the cases resulting in the greatest differences (refer to Appendix J) reveals that these generally occur:

1) at flow shut-off point,

2) during the first ¼ sec of data, or

3) at discontinuities in the curves.

Examination of the following tables, and associated plots, indicates that there is no significant G-effect upon the performance of the CSU-15/P. All deviations between static and G-stressed conditions are less than 0.2 and are probably not physiologically significant. It is significant that, with only one exception, all deviations over 0.1 occurred during the 1-sec fill and exhaust cycles, and are probably the product of suit-skin friction impeding the application or release of pressure on the force sensor.

4.4 British Mini Anti-G Suit

The "British Mini," an anti-G protective garment designed and produced for the British RAF, is a standard pneumatic bladder type anti-G suit; but it is cut off just above the knees, and does not have calf bladders. This suit has three bladders, located on the abdomen, and on the left and right thigh, respectively.

Suit adjustment is accomplished by lacings on the waist and thighs. The mini is connected to the anti-G valve through a flexible hose by a standard breakaway quick-disconnect fitting.

Data from Appendix K: "British Mini Anti-G Suit Data Curves," are presented in the following subsections in summary and table form. Before these data are examined, the following considerations must be noted:

1) Flow requirements and suit volumes cannot be compared with the suit volume data, as the test conditions are not the same. The volume tests were run with evacuated suits, while the fill and exhaust tests were made using suits filled to atmospheric pressure.

2) The 2-sec fill rate was used for valve flow delivery requirements to the suit--representing approximately a 4 G/sec G-onset rate.

3) Flow data curves (1- and 2-sec fill rates) generally show a fill time of ¼ to ½ sec longer than the stated fill time. This difference is a result of modeling techniques and data discontinuities, and also of a statistical variation in flow control valve settings.

TABLE 20. THE 1-SEC AND 20-SEC FILL-RATE TESTS OF THE CSU-15/P ANTI-G SUIT (3M*)

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
		[FILL RATE = 1 SEC; G-FORCE = 2 G_z]				
MIN	0.03104	0.02215	0.01041	0.02975	0.01556	0.01282
MID	0.07383	0.05414	0.15545	0.06046	0.07149	0.06568
MAX	0.08597	0.08407	0.06404	0.05468	0.05694	0.04836
		[FILL RATE = 1 SEC; G-FORCE = 10 G_z]				
MIN	0.15128	0.13348	0.13794	0.14265	0.13895	0.14526
MID	0.06238	0.03128	0.15398	0.09719	0.06503	0.04958
MAX	0.06967	0.02906	0.16989	0.04453	0.03877	0.04040
		[FILL RATE = 20 SEC; G-FORCE = 2 G_z]				
MIN	0.00960	0.02081	0.01075	0.00949	0.01147	0.01015
MID	0.01268	0.01134	0.00982	0.05520	0.01572	0.01278
MAX	0.00485	0.00812	0.02262	0.02636	0.01014	0.00826
		[FILL RATE = 20 SEC: G-FORCE = 10 G_z]				
MIN	0.02041	0.02138	0.01790	0.01283	0.02280	0.02006
MID	0.01209	0.02733	0.02995	0.07272	0.02068	0.01607
MAX	0.01918	0.02791	0.15220	0.04190	0.01123	0.01806

*3M refers to three suit sizes.

TABLE 21. THE 1-SEC AND 20-SEC EXHAUST-RATE TESTS OF THE CSU-15/P ANTI-G SUIT (3M*)

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
		[EXHAUST RATE = 1 SEC; G-FORCE = 2 G_z]				
MIN	0.01532	0.01990	0.07972	0.02724	0.05765	0.01380
MID	0.01616	0.01949	0.03405	0.02574	0.02802	0.03140
MAX	0.03497	0.02447	0.03440	0.00744	0.02211	0.01921
		[EXHAUST RATE = 1 SEC; G-FORCE = 10 G_z]				
MIN	0.02191	0.03139	0.05508	0.04931	0.08059	0.03417
MID	0.07311	0.03901	0.11575	0.19038	0.04433	0.05278
MAX	0.04599	0.02681	0.04594	0.01863	0.02856	0.03462
		[EXHAUST RATE = 20 SEC; G-FORCE = 2 G_z]				
MIN	0.00588	0.01415	0.01467	0.00501	0.01002	0.00688
MID	0.00558	0.01528	0.00535	0.01827	0.01138	0.00688
MAX	0.00476	0.03878	0.07374	0.00957	0.07213	0.02615
		[EXHAUST RATE = 20 SEC; G-FORCE = 10 G_z]				
MIN	0.01627	0.01908	0.02937	0.01006	0.01790	0.01510
MID	0.01435	0.02476	0.01882	0.01280	0.02718	0.01787
MAX	0.01682	0.03445	0.05050	0.02405	0.03580	0.02102

*3M refers to three suit sizes.

In addition to the curves and the tables in the following subsections, each set of curves in Appendix K is preceded by a table containing the minimum and maximum suit pressure, force gage readings, flow readings, and representative deviations from the mean of the data.

Lastly, while absolute maximum and minimum force gage readings and suit-pressure readings are presented in table form in Appendix K, the actual curves are normalized curves. Relative comparisons are necessary, since absolute force gage readings are a function of variables other than suit pressure and fill rate. Other variables include area of suit contact with the force gage, bladder form, and suit fit.

4.4.1 Suit-Volume Tests

Listed in Table 22 are the volumes (in liters) for several configurations of the British Mini, medium-regular size. Only one suit (medium-regular) of this type was available for testing. The mean values of the volume and the three standard deviations are based on a sample of five runs for each suit configuration. The volumes were calculated at a suit pressure of 5 psig. The same data are shown in Figure 9 as points on the 5-psig ordinate.

The various configurations of the medium-regular size were obtained by adjusting the suit on a fiberglass mannequin to a looser than normal fit, a tighter than normal fit, and a normal fit. The suit was also tested while properly fitted to a human subject. These volumes were used to establish an average volume for the later tests.

Shown in Table 23 and Figure 9 are the "stretch" volumes of a British Mini medium-regular suit mounted on a fiberglass mannequin. These data were obtained by evacuating the suit with a mild vacuum, then raising the suit pressure in 1-psig steps, and calculating the suit volume at each step. Three standard deviations from the mean are also shown.

It should be noted that the indicated suit volume increases rapidly until a pressure of about 2 psig is attained. This increase is primarily due to the volume of air required to "fill out" the suit from the evacuated condition. From 2 to 10 psig, the suit volume increases in a reasonably linear fashion at a rate of approximately 0.18 liter/psig.

In Tables 24 and 25, and Figure 10, are shown the same data as in Tables 22 and 23, and Figure 9, except that anti-G suit volumes are expressed in terms of standard air volume (SAV); i.e., the volume, in liters, occupied by the air in the suit at 14.7 psia. This information is useful in calculating suit leak flow.

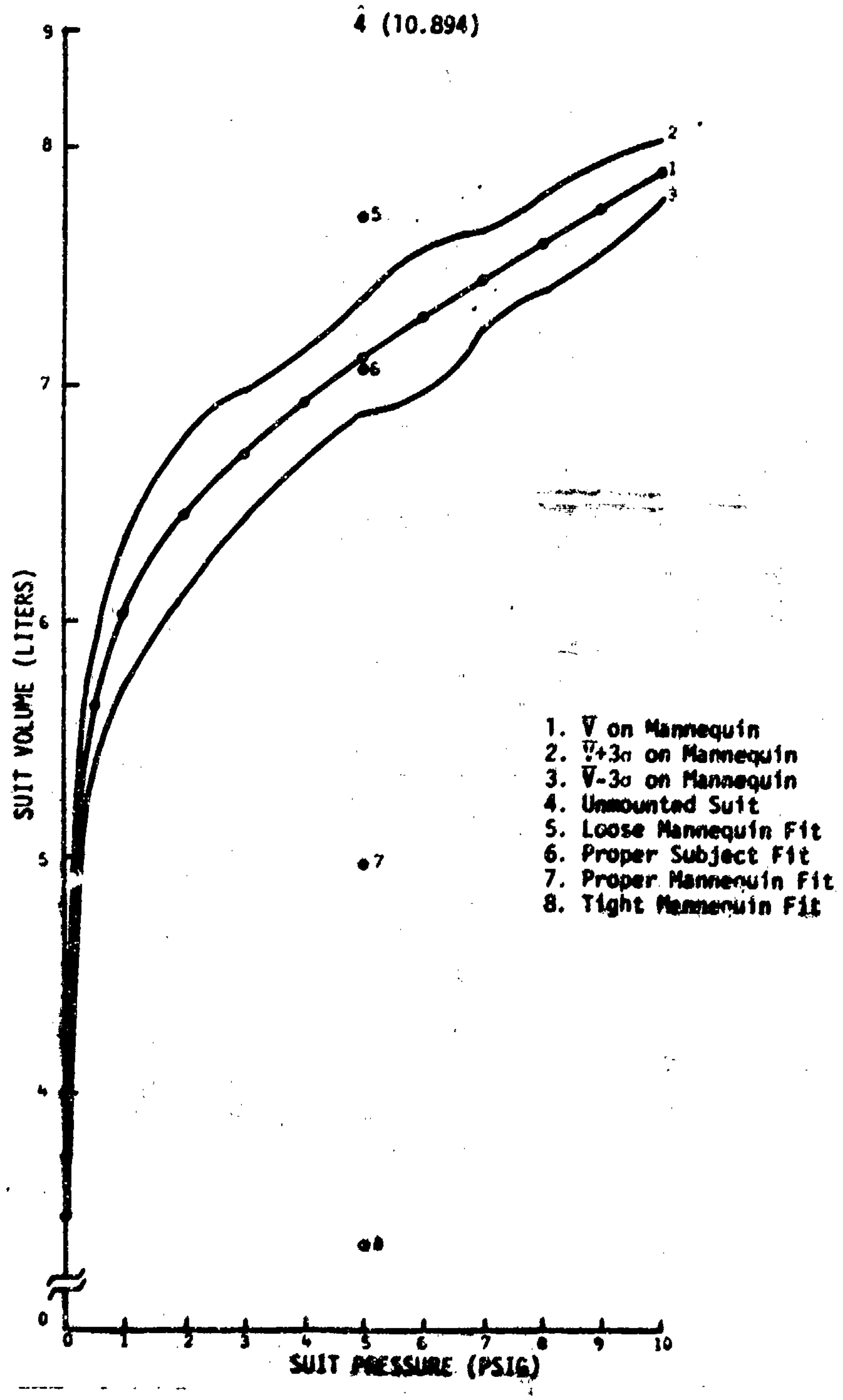

Figure 9. Volume of the British anti-G mini-suit (medium-regular size).

TABLE 22. VOLUMES OF THE BRITISH ANTI-G MINI-SUIT
(MEDIUM-REGULAR SIZE)

SUIT SIZE*	CONFIGURATION	VOLUMES (liters)					$\overline{V}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Medium-Regular	Unmounted	10.870	10.888	10.901	10.896	10.916	10.894	0.050
Medium-Regular	Mannequin: Loose fit	7.718	7.753	7.738	7.731	7.767	7.741	0.056
Medium-Regular	Mannequin: Proper fit	4.952	4.954	4.959	5.043	5.032	4.988	0.136
Medium-Regular	Mannequin: Tight fit	3.352	3.332	3.448	3.429	3.368	3.386	0.150
Medium-Regular	Subject: Proper fit	7.040	7.159	7.026	7.212	7.134	7.114	0.238

*Only the Medium-Regular size suit was available.

TABLE 23. STRETCH VOLUMES OF THE BRITISH ANTI-G MINI-SUIT (MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_V (psig)	SUIT STRETCH VOLUMES (liters)					$\overline{V}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
0+	3.736	3.631	3.880	3.721	3.778	3.749	0.272
0.5	5.497	5.589	5.652	5.749	5.689	5.635	0.290
1.0	5.898	5.975	6.013	6.132	6.144	6.032	0.315
2.0	6.269	6.450	6.443	6.527	6.534	6.445	0.320
3.0	6.568	6.715	6.692	6.797	6.766	6.708	0.265
4.0	6.803	6.903	6.904	6.993	6.972	6.915	0.223
5.0	6.987	7.106	7.116	7.214	7.166	7.118	0.254
6.0	7.110	7.265	7.257	7.377	7.329	7.268	0.302
7.0	7.338	7.431	7.425	7.531	7.477	7.440	0.214
8.0	7.496	7.610	7.579	7.667	7.628	7.596	0.193
9.0	7.645	7.770	7.721	7.819	7.773	7.746	0.198
10.0	7.852	7.918	7.894	7.959	7.926	7.910	0.119

TABLE 24. STANDARD AIR VOL THE BRITISH ANTI-G MINI-SUIT (MEDIUM SIZE)

SUIT SIZE	CONFIGURATION	STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Medium-Regular	Unmounted	14.605	14.628	14.646	14.639	14.666	14.637	0.067
Medium-Regular	Mannequin: Loose fit	10.391	10.438	10.392	10.383	10.431	10.407	0.076
Medium-Regular	Mannequin: Proper fit	6.650	6.653	6.660	6.789	6.775	6.705	0.210
Medium-Regular	Mannequin: Tight fit	4.502	4.463	4.642	4.616	4.524	4.549	0.229
Medium-Regular	Subject: Proper fit	9.411	9.594	9.416	9.690	9.585	9.539	0.366

TABLE 25. STRETCH STANDARD AIR VOLUMES OF THE BRITISH ANTI-G MINI-SUIT (MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_v (psig)	STRETCH STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
0+	3.739	3.634	3.883	3.724	3.780	3.752	0.272
0.5	5.705	5.781	5.846	5.946	5.884	5.832	0.279
1.0	6.303	6.385	6.426	6.553	6.566	6.445	0.337
2.0	7.128	7.334	7.326	7.422	7.430	7.328	0.365
3.0	7.919	8.097	8.069	8.195	8.158	8.088	0.319
4.0	8.670	8.797	8.798	8.912	8.885	8.812	0.284
5.0	9.383	9.543	9.557	9.688	9.623	9.559	0.342
6.0	10.035	10.255	10.244	10.414	10.345	10.259	0.429
7.0	10.862	10.999	10.490	11.148	11.066	11.013	0.316
8.0	11.609	11.786	11.737	11.874	11.814	11.764	0.299
9.0	12.365	12.567	12.487	12.645	12.572	12.527	0.319
10.0	13.238	13.350	13.309	13.418	13.362	13.335	0.201

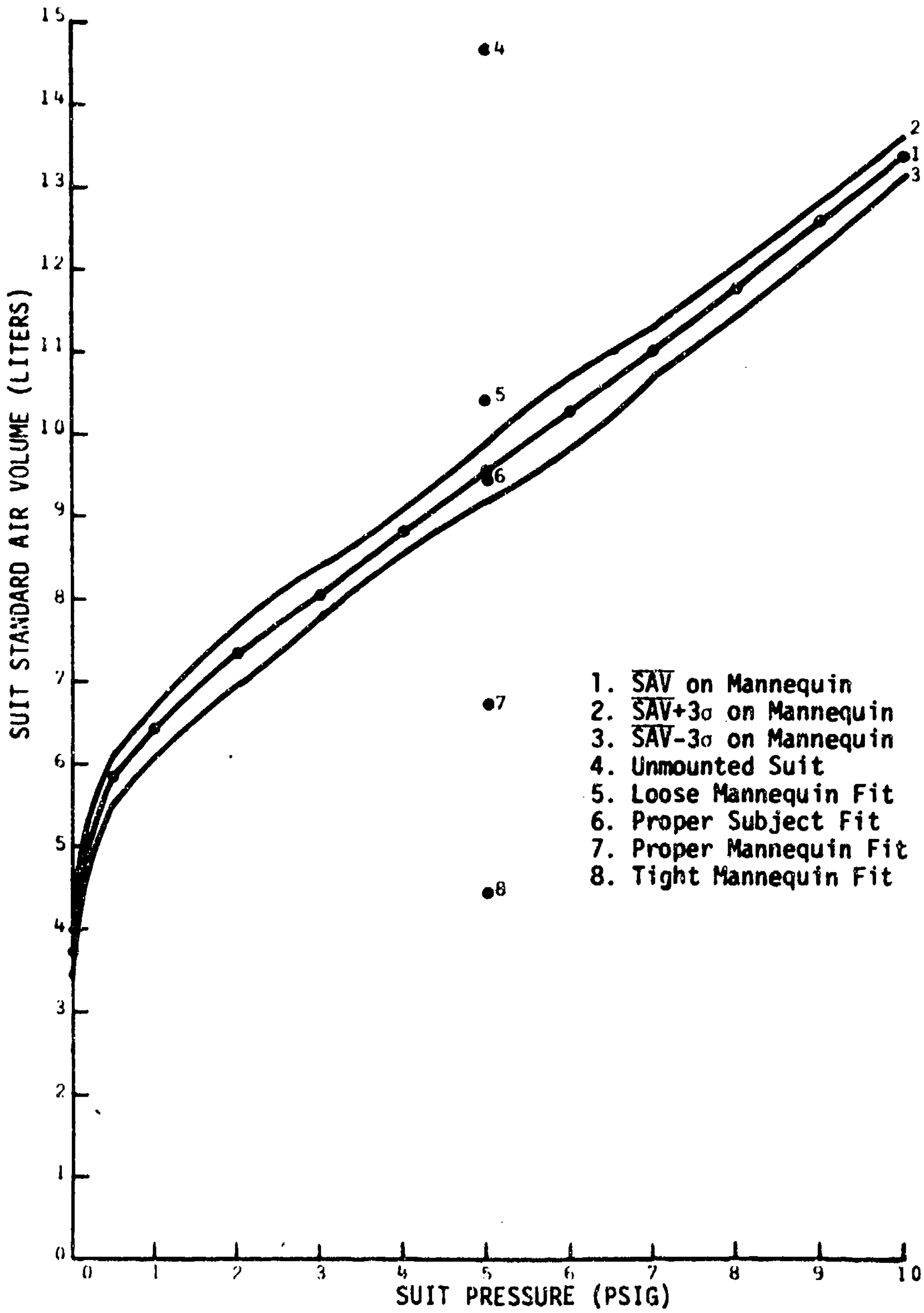

Figure 10. Standard air volume of the British anti-G mini-suit (medium-regular size).

4.4.2 Flow Impedance

Phases II and III were run on only the middle ("mid") volume (7.0 liters) suit configuration. The mid-volume for the suit was close to the maximum ("max") obtainable (7.7 liters) and, therefore, would not have made a significant change from mid- to max-volume data. Since max-volume data were not taken, there was no point in taking min-volume data for comparative purposes.

At all experimental fill rates, the British Mini filled to near required pressures.

4.4.3 Max Fill Rates

The 1-sec and 20-sec fill rates of the British Anti-G Mini-suit are compared in Table 26.

TABLE 26. FLOW RATES OF THE BRITISH ANTI-G MINI-SUIT

SUIT VOL.	F_M	$\bar{F}_M$	F_M	F_M
	[1 sec]		[20 sec]	
Mid	36.7	26.8	31.2	4.6

F_M = the peak flow measured during the 5 runs.

$\bar{F}_M$ = the average maximum flow.

4.4.4 Flow Requirements

The British Mini required a steady flow of 12 SCFM and a peak flow of 38 SCFM to fill the suit in the required 2-sec time interval. Therefore, any valve used with the British Mini should be able to deliver these flow rates for G-onset rates approaching 4 G/sec.

4.4.5 Normalized Parameters

The normalized force gage and suit pressure are very tightly grouped at all fill rates. This finding indicates that the British Mini fills and bleeds nearly as a unit, with all bladders following the input suit pressure.

4.4.6. G-Force Effects

The British Mini was run through identical 1-sec and 20-sec fill and bleed tests under static conditions, 2 G and 10 G. Tables 27 and 28 contain the maximum normalized difference for the respective parameters under G and static conditions. Examination of graphs of the cases resulting in the greatest differences (refer to Appendix K) reveals that these generally occur:

TABLE 27. THE 1-SEC AND 20-SEC FILL-RATE TESTS OF THE BRITISH (RAF) ANTI-G MINI-SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
[FILL RATE = 1 sec; G-FORCE = 2 G_z]						
MID	0.13988	0.20991	0.44864	0.08826	0.0	0.0
[FILL RATE = 1 SEC; G-FORCE = 10 G_z]						
MID	0.38114	0.50220	0.28225	0.30381	0.0	0.0
[FILL RATE = 20 SEC; G-FORCE = 2 G_z]						
MID	0.3553	0.03067	0.02975	0.03470	0.0	0.0
[FILL RATE = 20 SEC; G-FORCE = 10 G_z]						
MID	0.01743	0.01858	0.02210	0.01809	0.0	0.0

TABLE 28. THE 1-SEC AND 20-SEC EXHAUST-RATE TESTS OF THE BRITISH (RAF) ANTI-G MINI-SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
[EXHAUST RATE = 1 SEC; G-FORCE = 2 G_z]						
MID	0.02102	0.04944	0.01237	0.01325	0.0	0.0
[EXHAUST RATE = 1 SEC; G-FORCE = 10 G_z]						
MID	0.01263	0.13336	0.01688	0.00855	0.0	0.0
[EXHAUST RATE = 20 SEC; G-FORCE = 2 G_z]						
MID	0.00789	0.01692	0.00996	0.00832	0.0	0.0
[EXHAUST RATE = 20 SEC; G-FORCE = 10 G_z]						
MID	0.01565	0.01737	0.01699	0.01841	0.0	0.0

1) at flow shut-off points,

2) during the first ¼ sec of data, or

3) at discontinuities in the curves.

Examination of the following tables, and associated plots, indicates that there is no significant G-effect upon the performance of the British Mini. All deviations between static and G-stressed conditions are less than 0.2 (except for pressure and bladder force on the 1-sec fills), and are probably not physiologically significant. The 1-sec fills, which had values ranging from 0.088 and 0.502, registered these values at the curve peaks. This variation is the result of valve shut-off characteristics, suit-skin friction effects, and the statistical variation which is present during high fill rates. It is significant that, with only one exception, all deviations over 0.1 occurred during the 1-sec fill and exhaust cycles.

4.5 USAF Lower Body Full Pressure (LBFP) Anti-G Suit

The Lower Body Full Pressure (LBFP) anti-G suit, designed and produced for the U.S. Air Force, uses a maximum of 6 psig. This suit uses large pneumatic bladders which completely surround the legs and abdominal area and apply pressure over the entire lower body. The LBFP, which connects to the pressure source (i.e., an anti-G valve) through a flexible hose and a standard breakaway quick disconnect fitting, may use a standard anti-G valve; but, because of its large volume, extremely high flow rates from the valve are required to pressurize the suit rapidly.

Data from Appendix L: "LBFP Anti-G Suit Data Curves," are presented in the following subsections in summary and in tables. Before these data are examined, the following considerations must be noted:

1) Flow requirements and suit volumes cannot be compared with the suit-volume data, as the test conditions are not the same. The volume tests were run with evacuated suits, while the fill and exhaust tests were made with suits filled to atmospheric pressure.

2) The 2.5-sec fill rate was used for valve flow delivery requirements to the suit, representing approximately a 3.5 G/sec G-onset rate--the maximum fill rate of which the LBFP is capable.

3) Flow data curves generally show a fill time of ¼ to ½ sec longer than the stated fill time. This difference is a result of modeling techniques and data discontinuities, and also of a statistical variation in flow control valve settings.

In addition to the curves and the tables in the following subsections, each set of curves in Appendix L is preceded by a table containing the minimum and maximum suit pressures, force gage readings, flow readings, and representative deviations from the mean of the data.

Lastly, while absolute maximum and minimum force gage readings and suit-pressure readings are presented in tables in Appendix L, the actual curves are normalized curves. Relative comparisons are necessary, because absolute force gage readings are a function of variables other than suit pressure and fill rate. Other variables include area of suit contact with the force gage, bladder form, and suit fit.

4.5.1 Suit-Volume Tests

Listed in Table 29 are the volumes (in liters) of various configurations of the LBFP suit. Only one size of the LBFP suit was available for test. The mean values of the volume and the three standard deviations are based on a sample of five runs for each suit configuration. The volumes were calculated at a suit pressure of 2.5 psig. The same data are shown in Figure 11 as points on the 2.5-psig ordinate.

The various configurations of the medium-regular size were obtained by adjusting the suit on a fiberglass mannequin to: a looser than normal fit, a tighter than normal fit, and a normal fit. The suit was also tested while properly fitted to a human subject. These volumes were used to establish an average volume for the later tests.

Listed in Table 30 are the "stretch" volumes of an LBFP medium-regular suit mounted on a fiberglass mannequin. These data (Fig. 11) were obtained by evacuating the suit with a mild vacuum, then raising the suit pressure in ½-psig steps, and calculating the suit volume at each step. Three standard deviations from the mean are also shown.

It should be noted that the indicated suit volume increases rapidly until a pressure of about 2 psig is attained. This increase is primarily due to the volume of air required to fill out the suit from the evacuated condition. From 2 to 5 psig, the suit volume increases in a reasonably linear fashion at a rate of approximately 0.73 liter/psig.

In Tables 31 and 32, and Figure 12, are shown the same data as in Tables 29 and 30, and Figure 11, except that anti-G suit volumes are expressed in terms of standard air volume (SAV); i.e., the volume, in liters, occupied by the air in the suit at 14.7 psia. This information is useful in calculating suit leak flow.

4.5.2 Flow Impedance

The LBFP suit could not be filled to required pressures at 1- and 2-sec fill rates. The first set of data was taken at 2.5 sec, the fastest rate at which the LBFP could be filled. This suit was also tested at a 4-sec fill rate. After testing at the 4-sec rate was completed, the LBFP suit incurred a failure (a high leak rate) which precluded further testing of this suit.

TABLE 29. THE VOLUMES OF THE USAF LOWER BODY FULL PRESSURE (LBFP) ANTI-G SUIT

SUIT SIZE*	CONFIGURATION	VOLUMES (liters)					$\overline{V}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Medium-Regular	Unmounted	46.807	46.960	47.151	47.445	47.426	47.158	0.844
Medium-Regular	Mannequin: Loose fit	23.175	23.473	23.454	23.959	24.000	23.612	1.067
Medium-Regular	Mannequin: Proper fit	19.197	19.355	19.599	19.628	19.871	19.530	0.783
Medium-Regular	Mannequin: Tight fit	17.255	17.630	17.659	17.757	17.934	17.647	0.748
Medium-Regular	Subject: Proper fit	22.775	22.703	22.667	22.441	22.609	22.639	0.380

*Only one suit of this type was available for test.

TABLE 30. STRETCH VOLUMES OF THE USAF LBFP ANTI-G SUIT (MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_V (psig)	SUIT STRETCH VOLUMES (liters)					$\overline{V}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
0+	*4.585	8.461	7.911	8.748	9.802	8.755	2.517
0.5	16.039	17.180	17.316	15.441	17.205	16.636	2.539
1.0	18.316	19.115	19.160	17.981	19.364	18.787	1.806
1.5	19.448	20.224	20.433	19.414	20.444	19.993	1.561
2.0	20.406	21.030	21.447	20.472	21.383	20.948	1.474
2.5	21.117	21.824	22.065	21.342	22.226	21.715	1.417
3.0	21.901	22.492	22.662	22.218	22.958	22.446	1.219
3.5	22.534	23.182	23.407	22.985	23.663	23.154	1.287
4.0	23.315	23.884	24.106	23.820	24.390	23.903	1.191
4.5	23.981	24.493	24.909	24.589	25.193	24.633	1.372
5.0	24.690	25.232	25.517	25.359	25.857	25.331	1.284

LBFP = Lower Body Full Pressure.
*Supplemental data indicate this datum is in error and is discarded when calculating $\overline{V}$ and 3σ.

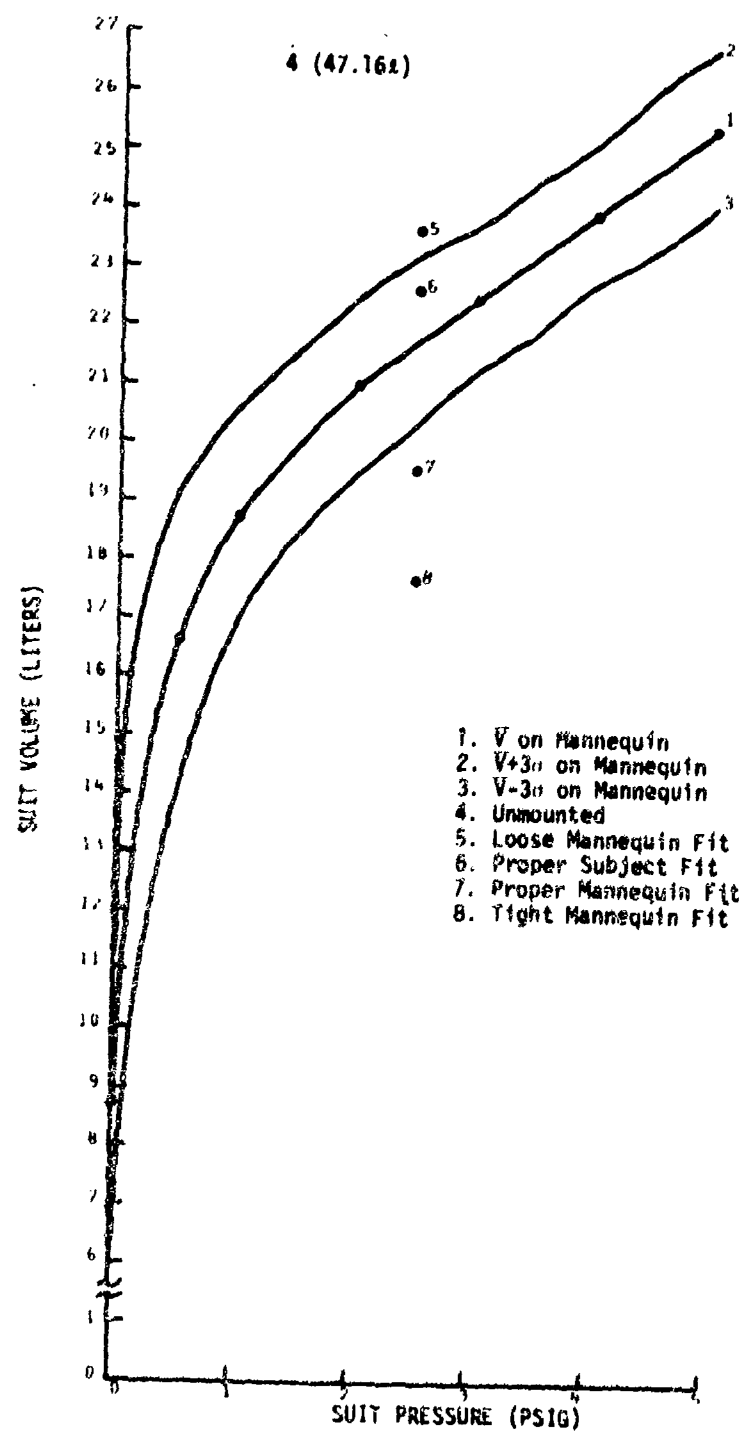

Figure 11. Volume of the USAF LBFP anti-G suit (medium-regular size).

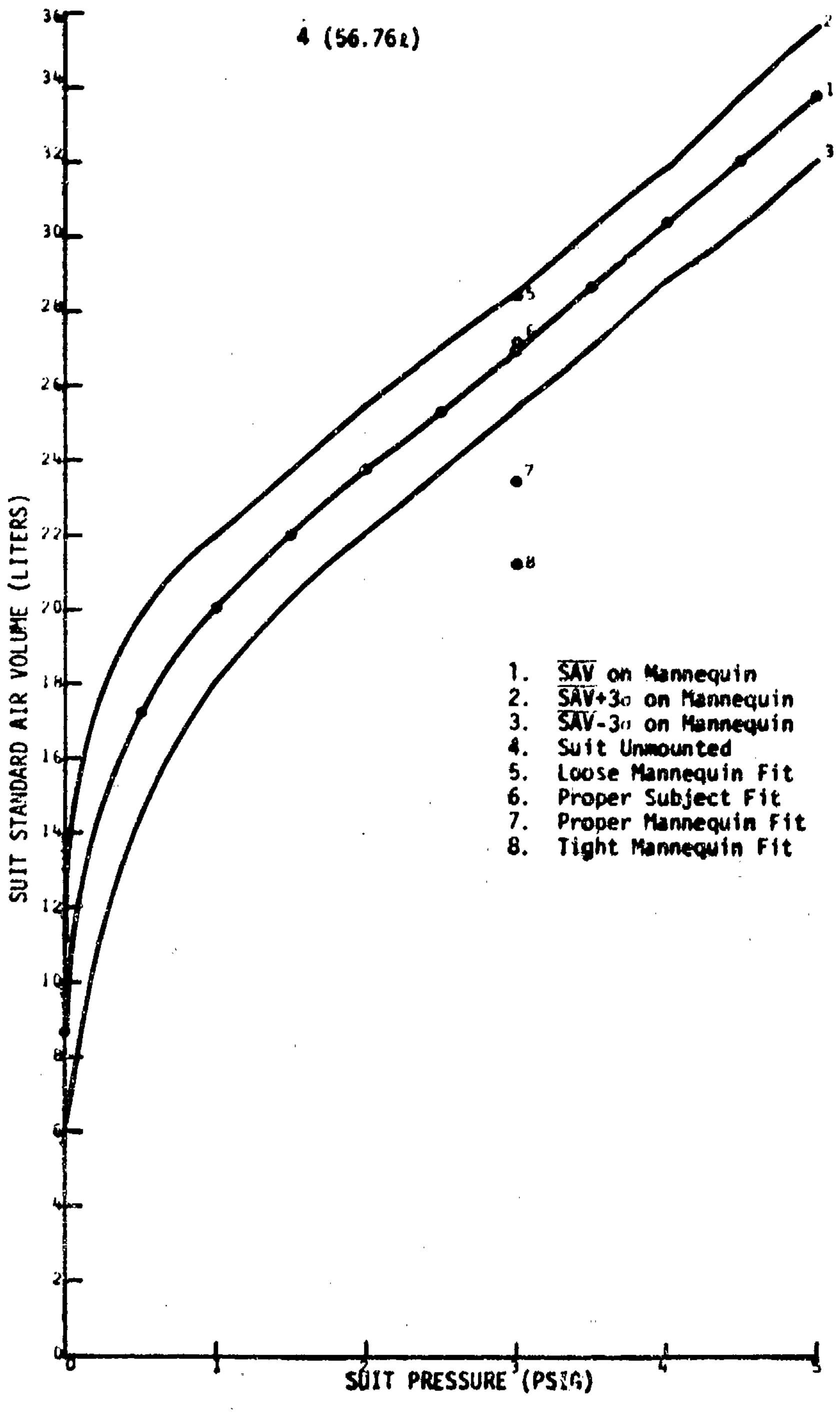

Figure 12. Standard air volume of the USAF LBFP anti-G suit (medium-regular size).

TABLE 31. STANDARD AIR VOLUMES OF THE USAF LBFP ANTI-G SUIT

SUIT SIZE*	CONFIGURATION	STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Medium-Regular	Unmounted	56.404	56.427	56.656	57.172	57.149	56.762	1.132
Medium-Regular	Mannequin: Loose fit	27.926	28.285	28.262	28.871	28.920	28.453	1.286
Medium-Regular	Mannequin: Proper fit	23.109	23.299	23.593	23.628	23.988	23.523	1.010
Medium-Regular	Mannequin: Tight fit	20.771	21.223	21.258	21.376	21.650	21.256	0.956
Medium-Regular	Mannequin: Proper fit	27.441	27.357	27.314	27.041	27.244	27.280	0.454

*Only one suit of this type was available for test.

TABLE 32. STRETCH STANDARD AIR VOLUMES OF THE USAF LBFP ANTI-G SUIT (MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_v (psig)	STRETCH STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
0+	4.588*	8.467	7.916	8.754	9.808	8.736	2.384
0.5	16.582	17.761	17.901	15.964	17.788	17.199	2.625
1.0	19.555	20.407	20.456	19.198	20.675	20.058	1.928
1.5	21.421	22.275	22.505	21.385	22.519	22.021	1.719
2.0	23.166	23.874	24.348	23.244	24.278	23.782	1.673
2.5	24.687	25.513	25.794	24.953	25.987	25.387	1.657
3.0	26.343	27.055	27.258	26.729	27.619	27.001	1.468
3.5	27.867	28.668	28.946	28.430	29.268	28.636	1.595
4.0	29.621	30.344	30.625	30.269	30.992	30.370	1.518
4.5	31.277	31.946	32.488	32.079	32.866	32.131	1.796
5.0	33.037	33.763	34.144	33.940	34.607	33.898	1.727

*Supplemental data indicate that this datum is in error and is discarded when calculating $\overline{SAV}$ and 3σ.

4.5.3 Maximum (Max) Fill Rates

The 2.5-sec and 4-sec fill rates of the USAF LBFP anti-G suit are compared in Table 33 for the mid-size suit.

TABLE 33. FLOW RATES OF THE USAF LBFP ANTI-G SUIT

SUIT VOL.	F_M	$\bar{F}_M$	F_M	$\bar{F}_M$
	[2.5 sec]		[4 sec]	
Mid	38.3	18	38.6	11

F_M = the peak flow measured during the 5 runs.

$\bar{F}_M$ = the average maximum flow.

4.5.4 Flow Requirements

The LBFP could not be filled at a 2-sec fill rate. The suit required a steady flow of 18 SCFM and a peak flow of 38 SCFM to fill the suit in a 2.5-sec time interval. Therefore, any valve used with the LBFP should be able to deliver these flow rates for G-onset rates approaching 3.5 G/sec.

4.5.5 Normalized Parameters

The normalized force gages profiles are very tight (e.g., grouped) at all fill rates. This finding indicates that the LBFP fills and bleeds as a unit, with all areas following the input suit pressure. The suit pressure generally leads the force gages significantly, due to the large suit size and to the flows required to fill the suit.

4.5.6 G-Force Effects

The LBFP was run through identical 2.5-sec fill and bleed tests under static conditions, 2 G and 10 G. Appendix L contains the static and G-effects plots. Examination of these graphs reveals that differences generally occur:

1) at flow shut-off point,

2) during the first ¼ sec of data, or

3) at discontinuities in the curves.

These plots indicate that there is no significant G-effect upon the performance of the LBFP.

4.6 Pneumatic Lever Anti-G Suit

The Pneumatic Lever Anti-G suit ("Capstan suit") was built for the U.S. Air Force. This garment uses the pneumatic capstan principle of operation. A flexible hose extends down the side of each leg and is connected to the suit fabric by interdigitized tapes; as pressure expands the hose, the suit fabric is drawn tighter about the limb. These capstans require higher than normal pressure (0 - 50 psig), and are connected to a special anti-G valve by a flexible hose and breakaway quick-disconnect fitting. Two sets of lacing adjustments are provided on each calf, and three on each thigh, so that the capstan size can be adjusted to the desired ratio of capstan diameter to limb diameter. This suit is also equipped with a standard pneumatic abdominal bladder which is pressurized through a separate hose by a standard anti-G valve.

Data from Appendix M: "Pneumatic Lever Anti-G Suit Data Curves," are presented in the following subsections in summary and in tables. Before examining these data, the following considerations must be noted:

1) Flow requirements and suit volumes cannot be compared with the suit-volume data, as the test conditions are not the same. The volume tests were run with evacuated suits, while the fill and exhaust tests were made using suits filled to atmospheric pressure.

2) The 2-sec fill rate was used for valve flow delivery requirements to the suit, representing approximately a 4 G/sec G-onset rate.

3) Flow data curves (1- and 2-sec fill rates) generally show a fill time of ¼ to ½ sec longer than the stated fill time. This difference is a result of modeling techniques and data discontinuities, and also of a statistical variation in flow control valve settings.

In addition to the curves and the tables in the following subsections, each set of curves in Appendix M is preceded by a table containing the minimum and maximum suit pressure, force gage readings, flow readings, and representative deviations from the mean of the data.

Lastly, while absolute maximum and minimum force-gage readings and suit-pressure readings are presented in tables in Appendix M, the actual curves are normalized. Relative comparisons are necessary, because absolute force-gage readings are a function of variables other than suit pressure and fill rate. Other variables include area of suit contact with the force gage, bladder form, and suit fit. Further testing of this suit was done under Contract Extension P00006 (of the TEHG Program), which produced data that directly relates suit pressure vs. force (refer to section 6 of this volume).

Since the Pneumatic Lever Suit has two separate bladder systems (i.e., abdominal bladder, and capstans) which are pressurized by separate valves, this suit was tested as two separate suits. Because of the effect each bladder system has on the volume of the other, all stretch volume measurements were made with the other bladder at maximum pressure. In other words, while the abdominal bladder was being tested, the capstans were maintained at 50 psig; and, while the capstans were being tested, the abdominal bladder was held at 10 psig.

4.6.1 Suit-Volume Tests

Listed in Table 34 are the volumes (in liters) for the various sizes of the Pneumatic Lever Suit capstans, and for several configurations of the medium-regular size. The mean values of the volume and the three standard deviations are based on a sample of five runs for each suit size. The volumes were calculated at a suit pressure of 25 psig. In Figure 13, the same data are shown as points on the 25-psig ordinate.

The various configurations of the medium-regular size were obtained by adjusting the suit on a fiberglass mannequin to a looser than normal fit, a tighter than normal fit, and a normal fit. The suit was also tested while properly fitted to a human subject. These volumes were used to establish an average volume for the later tests.

'isted in Table 35 is the "stretch" volume of the Pneumatic Lever Suit capstans (medium-regular suit) mounted on a fiberglass mannequin. These data (Fig. 13) were obtained by evacuating the suit with a mild

vacuum, then raising the suit pressure in 5-psig steps, and calculating the suit volume at each step. Three standard deviations from the mean are also shown.

In Tables 36 and 37, and Figure 14, are shown the same data as in Tables 35 and 36, and Figure 13, except that capstan volumes are expressed in terms of standard air volume; i.e., the volume, in liters, occupied by the air in the suit at 14.7 psia. This information is useful in calculating suit leak flow.

The various configuration volumes and stretch volumes for the abdominal bladder are shown in Tables 38 and 39, and in Figure 15.

In Tables 40 and 41 and Figure 16 are presented the same data, in terms of standard air volumes, as in Tables 38 and 39 and Figure 15.

It should be noted that the volume of the capstans of the Pneumatic Lever Anti-G Suit is variable over quite a wide range (1.2 - 7.2 liters in the extreme test cases) because of the large amount of adjustment of capstan diameter available. The primary purpose of this adjustment is not, however, for volumetric control, but to control the force ratio of the suit. It can be shown that the larger the ratio of capstan diameter to limb diameter, the greater the force applied to the limb; i.e., the larger the capstan diameter, the greater the force. Thus, in addition to varying the total force on the limb, the capstan design allows a retrograde inflation by making the capstan larger at the ankles than at the thigh.

Dynamic testing of the Pneumatic Lever Suit, abdominal bladder, and capstans was limited to two volume configurations--"Mid" and "Max." The Mid volume for the abdominal bladder was established by testing with 50 psig maintained in the capstans, the Max volume, by testing with the capstans vented. For capstan testing, the Mid volume was established by fitting the suit to the mannequin with a 6 to 1 ratio on the thigh and knee areas, and a 4 to 1 ratio on the calves, the Max volume, by fitting the suit to the mannequin with a continuous 4 to 1 ratio.

4.6.2 Flow Impedance

The Pneumatic Lever Suit filled to near required pressures at all experimental fill rates.

TABLE 34. CAPSTAN VOLUMES OF THE PNEUMATIC LEVER ANTI-G SUIT (CAPSTAN SUIT)

SUIT SIZE	CONFIGURATION	CAPSTAN VOLUMES (liters)					$\bar{V}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Small-Regular	Unmounted	5.090	5.205	5.195	5.275	5.260	5.205	0.218
Large-Regular	Unmounted	7.189	*	*	*	*	7.189	*
Medium-Regular	Unmounted	5.922	5.968	5.944	5.946	5.958	5.948	0.051
Medium-Regular	Mannequin: Loose fit	2.666	2.695	2.709	2.698	2.707	2.692	0.051
Medium-Regular	Mannequin: Proper fit	2.025	1.994	1.993	2.013	2.015	2.008	0.040
Medium-Regular	Mannequin: Tight fit	1.215	1.198	1.206	1.201	1.221	1.208	0.027
Medium-Regular	Subject: Proper fit	3.663	3.650	3.726	3.625	3.620	3.657	0.127

* After first run, capstan began to leak excessively, and further volume tests of this suit were not undertaken.

TABLE 35. CAPSTAN STRETCH VOLUMES OF THE PNEUMATIC LEVER ANTI-G SUIT
[capstan stretch, with 10 psig in abdominal bladder]
(MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_v (psig)	CAPSTAN STRETCH VOLUMES (liters)				$\overline{V}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]		
0+	0.485	0.688	1.108	1.268	0.887	1.089
2.5	1.840	1.798	1.776	1.868	1.821	0.124
5.0	1.968	1.920	1.929	1.860	1.919	0.134
10.0	2.149	2.113	2.132	2.111	2.126	0.053
15.0	2.287	2.270	2.220	2.257	2.259	0.085
20.0	2.404	2.393	2.385	2.410	2.398	0.031
25.0	2.505	2.526	2.498	2.503	2.508	0.035
30.0	2.627	2.640	2.614	2.529	2.628	0.030
35.0	2.766	2.754	2.754	2.743	2.754	0.027
40.0	2.910	2.868	2.895	2.896	2.892	0.052
45.0	3.044	3.025	3.061	3.036	3.042	0.044
50.0	3.251	3.178	3.238	3.186	3.213	0.109

TABLE 36. CAPSTAN STANDARD AIR VOLUMES OF THE PNEUMATIC LEVER ANTI-G SUIT

SUIT SIZE	CONFIGURATION	CAPSTAN STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3 (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Small-Regular	Unmounted	13.800	14.244	14.084	14.301	14.260	14 140	0.623
Large-Regular	Unmounted	19.432	*	*	*	*	19.432	*
Medium-Regular	Unmounted	16.055	16.181	16.115	16.121	16.234	16.141	0.205
Medium-Regular	Mannequin: Loose fit	7.183	7.261	7.297	7.266	7.293	7.260	0.137
Medium-Regular	Mannequin: Proper fit	5.455	5.358	5.368	5.422	5.427	5.406	0.124
Medium-Regular	Mannequin: Tight fit	3.293	3.231	3.269	3.254	3.309	3.271	0.092
Medium-Regular	Subject: Proper fit	9.902	9.866	10.123	9.675	9.785	9.870	0.498

*After first fun, capstan began to leak excessively, and further volume tests were not undertaken.

TABLE 37. CAPSTAN STRETCH STANDARD AIR VOLUMES OF THE PNEUMATIC LEVER ANTI-G SUIT
[capstan stretch, with 10 psig in abdominal bladder]
(MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_V (psig)	CAPSTAN STRETCH STANDARD AIR VOLUMES (liters)				$\overline{SAV}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]		
0+	0.485	0.688	1.109	1.269	0.888	1.090
2.5	2.185	2.105	2.079	2.186	2.139	0.165
5.0	2.639	2.575	2.587	2.494	2.574	0.180
10.0	3.615	3.554	3.586	3.551	3.577	0.090
15.0	4.628	4.593	4.568	4.567	4.589	0.085
20.0	5.685	5.659	5.639	5.700	5.671	0.081
25.0	6.777	6.835	6.759	6.771	6.786	0.101
30.0	8.005	8.043	7.964	8,011	8.016	0.098
35.0	9.372	9.332	9.329	9.294	9.332	0.095
40.0	10.850	10.696	10.795	10.801	10.786	0.193
45.0	12.392	12.313	12.458	12.357	12.380	0.183
50.0	14.339	14.017	14.284	14.055	14.174	0.484

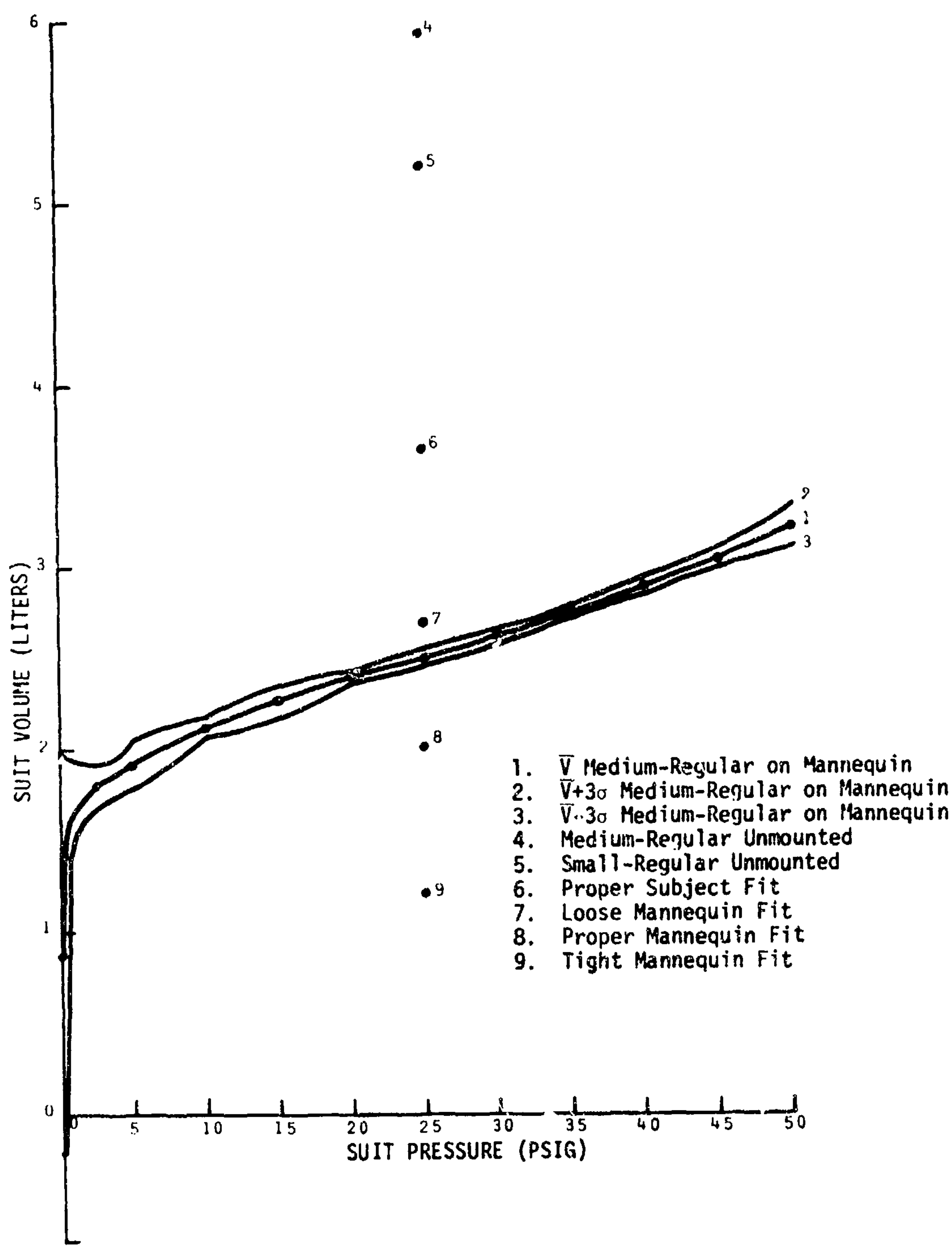

Figure 13. Capstan volume of the Pneumatic Lever Anti-G Suit.

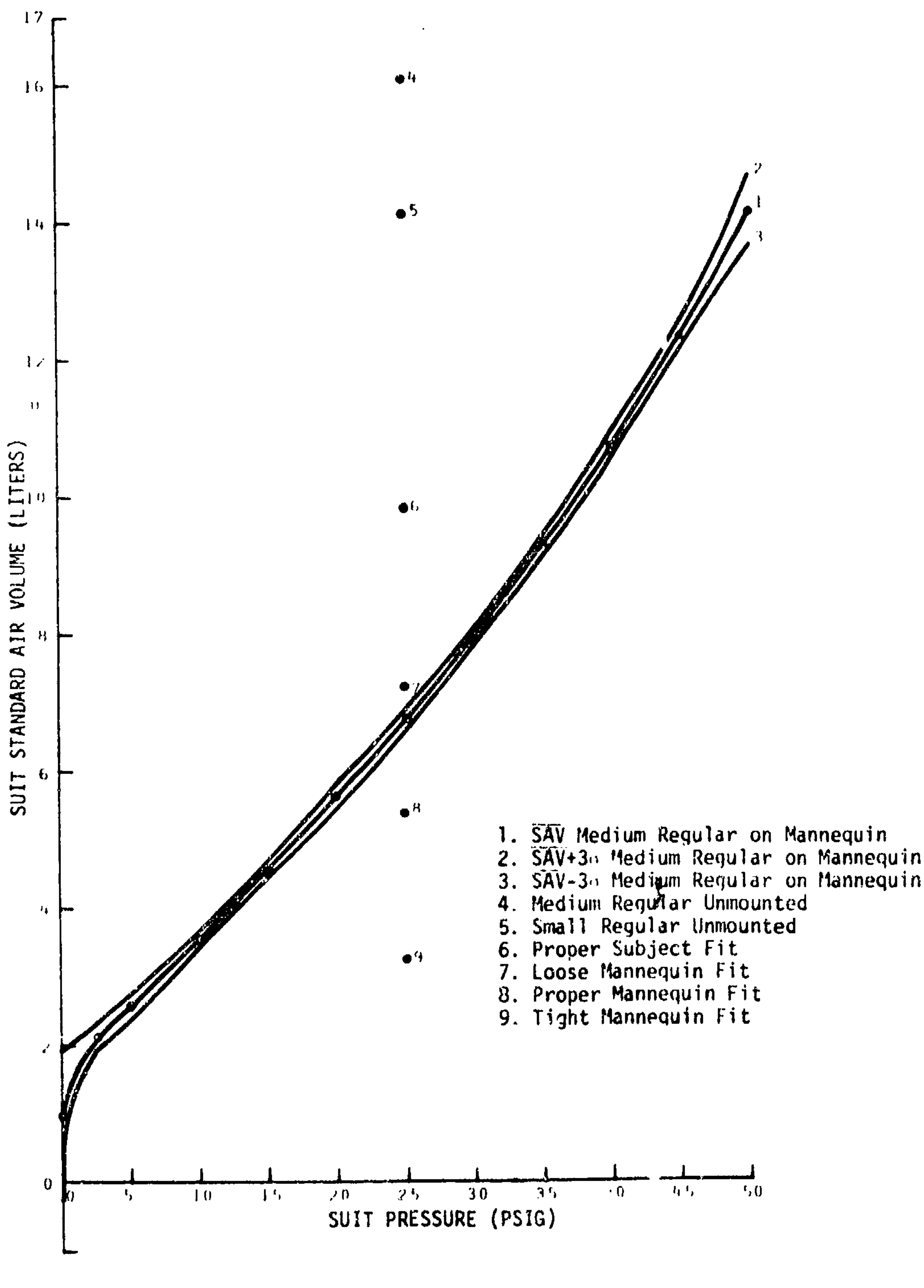

Figure 14. Capstan standard air volume of the Pneumatic Lever Anti-G Suit.

TABLE 38. ABDOMINAL BLADDER VOLUMES OF THE PNEUMATIC LEVER ANTI-G SUIT

SUIT SIZE	CONFIGURATION	VOLUMES (liters)					$\overline{V}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Small-Regular	Unmounted	2.986	2.977	2.952	2.958	2.964	2.967	0.040
Large-Regular	Unmounted	3.996	3.985	3.972	3.977	3.961	3.978	0.038
Medium-Regular	Unmounted	2.863	2.852	2.847	2.699	2.651	2.782	0.299
Medium-Regular	Mannequin: Loose fit	2.599	2.579	2.570	2.569	2.614	2.586	0.058
Medium-Regular	Mannequin: Proper fit	2.516	2.506	2.520	2.524	2.519	2.517	0.019
Medium-Regular	Mannequin: Tight fit	2.105	2.116	2.104	2.105	2.105	2.107	0.009
Medium-Regular	Subject: Proper fit	2.864	2.848	2.874	2.791	2.888	2.853	0.112

TABLE 39. STRETCH VOLUMES OF THE PNEUMATIC LEVER ANTI-G SUIT
[Abdominal bladder stretch, with 50 psig in capstans]
(MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_V (psig)	SUIT STRETCH VOLUMES (liters)					$\overline{V}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
0+	0.177	0.190	0.153	0.243	0.313	0.215	0.191
0.5	0.521	0.554	0.546	0.676	0.699	0.599	0.246
1.0	0.642	0.676	0.735	0.808	0.826	0.737	0.240
2.0	0.825	0.850	0.943	0.983	0.992	0.919	0.230
3.0	0.936	0.953	1.085	1.099	1.102	1.035	0.249
4.0	1.041	1.064	1.210	1.229	1.237	1.156	0.286
5.0	1.124	1.156	1.351	1.326	1.343	1.260	0.331
6.0	1.213	1.265	1.480	1.452	1.494	1.381	0.395
7.0	1.320	1.375	1.601	1.566	1.602	1.493	0.404
8.0	1.404	1.469	1.740	1.672	1.735	1.604	0.471
9.0	1.506	1.592	1.864	1.803	1.850	1.723	0.490
10.0	1.632	1.758	2.000	1.942	2.004	1.867	0.496

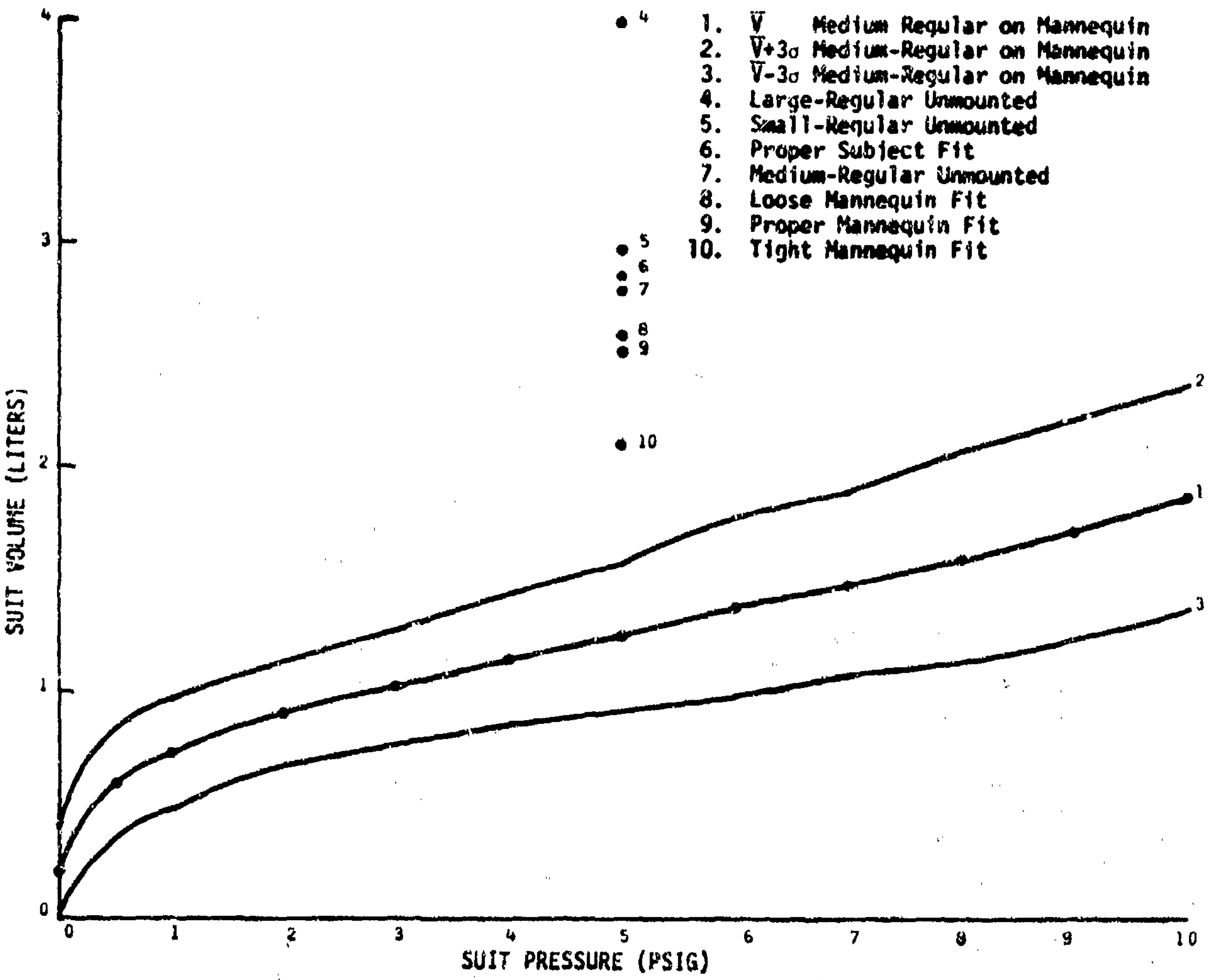

Figure 15. Abdominal bladder volume of the Pneumatic Lever Anti-G Suit.

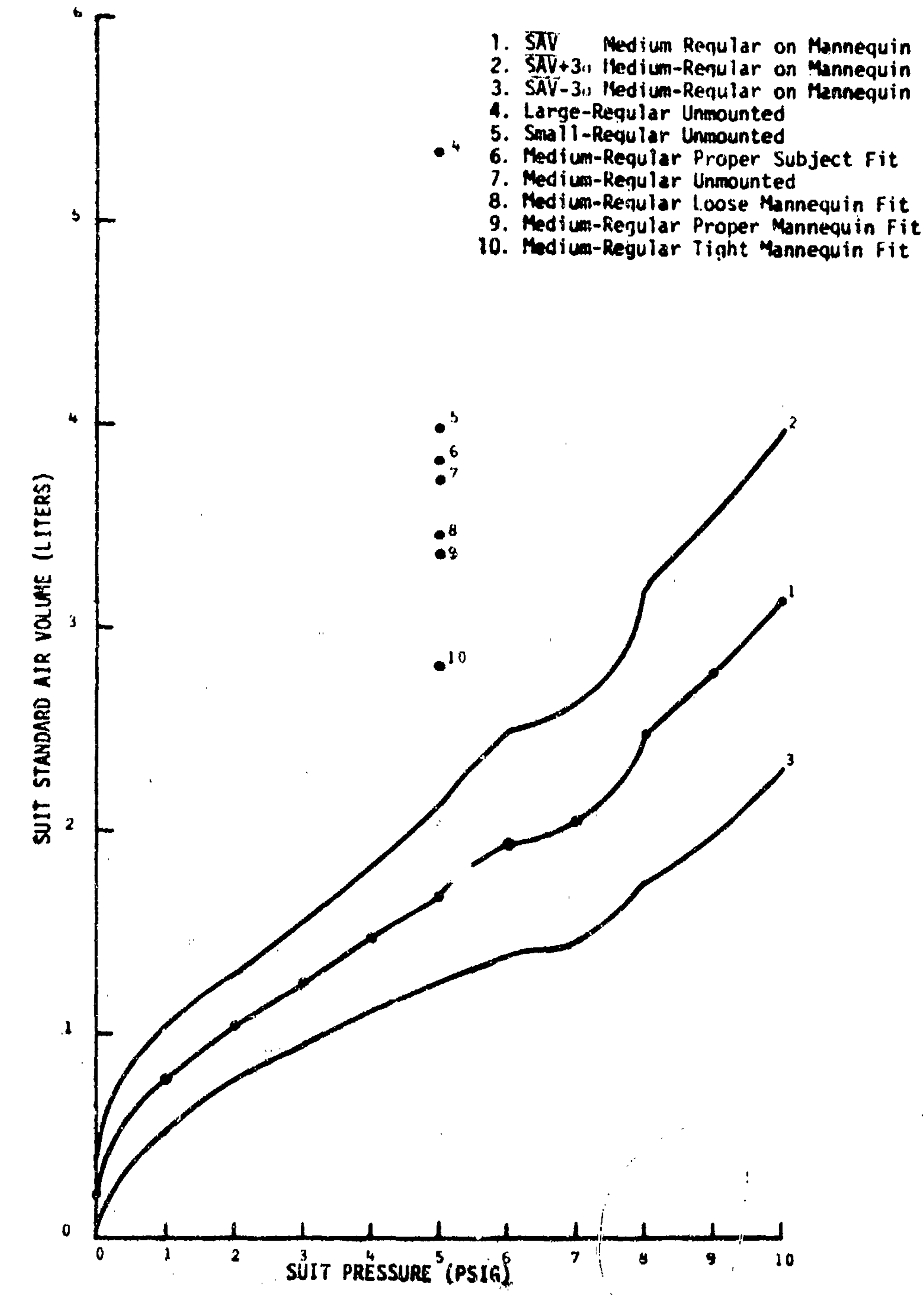

Figure 16. Standard air volume of the abdominal bladder in the Pneumatic Lever Anti-G Suit.

TABLE 40. STANDARD AIR VOLUMES OF THE ABDOMINAL BLADDER IN THE PNEUMATIC LEVER ANTI-G SUIT

SUIT SIZE	CONFIGURATION	STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
		[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
Small-Regular	Unmounted	4.029	4.005	3.972	3.980	3.988	3.995	0.068
Large-Regular	Unmounted	5.370	5.356	5.325	5.345	5.310	5.341	0.072
Medium-Regular	Unmounted	3.844	3.828	3.822	3.613	3.549	3.731	0.418
Medium-Regular	Mannequin: Loose fit	3.479	3.453	3.440	3.440	3.508	3.464	0.087
Medium-Regular	Mannequin: Proper fit	3.377	3.355	3.373	3.378	3.372	3.371	0.025
Medium-Regular	Mannequin: Tight fit	2.818	2.839	2.823	2.825	2.825	2.826	0.021
Medium-Regular	Subject: Proper fit	3.860	3.819	3.853	3.741	3.881	3.831	0.165

TABLE 41. STRETCH STANDARD AIR VOLUMES OF THE PNEUMATIC LEVER ANTI-G SUIT (Abdominal bladder stretch, with 50 psig in capstans) (MEDIUM-REGULAR SIZE, ON MANNEQUIN)

PRESSURE: P_V (psig)	STRETCH STANDARD AIR VOLUMES (liters)					$\overline{SAV}$ (liters)	3σ (liters)
	[Run #1]	[Run #2]	[Run #3]	[Run #4]	[Run #5]		
0+	0.177	0.190	0.153	0.243	0.314	0.215	0.192
0.5	0.539	0.573	0.564	0.699	0.723	0.620	0.254
1.0	0.685	0.722	0.785	0.863	0.883	0.788	0.258
2.0	0.937	0.967	1.071	1.117	1.128	1.044	0.262
3.0	1.128	1.148	1.307	1.324	1.327	1.247	0.299
4.0	1.326	1.355	1.541	1.564	1.574	1.472	0.363
5.0	1.508	1.551	1.612	1.779	1.801	1.690	0.444
6.0	1.709	1.783	2.085	2.047	2.105	1.946	0.556
7.0	1.950	2.032	2.365	2.314	2.357	2.206	0.597
8.0	2.170	2.271	2.689	2.585	2.681	2.479	0.727
9.0	2.431	2.569	3.009	2.910	2.987	2.781	0.792
10.0	2.746	2.957	3.362	3.266	3.372	3.141	0.832

4.6.3 Maximum (Max) Fill Rates (Abdominal Bladder)

The 1-sec and 20-sec fill rates for the two suit si[illegible]s are compared in Table 42.

TABLE 42. ABDOMINAL BLADDER FLOW RATES IN THE PNEUMATIC LEVER ANTI-G SUIT

SUIT VOL	F_M	$\bar{F}_M$	F_M	$\bar{F}_M$
	[1 sec]		[20 sec]	
Mid	9.3	5.4	2.65	0.30
Max	30.5	9.8	7.0	0.40

F_M = the peak flow measured during the 5 runs.

$\bar{F}_M$ = the average maximum flow.

4.6.4 Flow Requirements (Abdominal Bladder)

To fill the Pneumatic Lever Abdominal Bladder, in the required 2-sec time interval, necessitated a steady flow of 3.0 SCFM and a peak flow of 3.5 SCFM. Therefore, any valve used with this bladder should be able to deliver these flow rates for G-onset rates approaching 4 G/sec.

4.6.5 Normalized Parameters (Abdominal Bladder)

The normalized force gage and bladder pressure profiles are ver[illegible] at all fill rates. This finding indicates that the abdominal bladder [illegible] and bleeds follow the input suit pressure closely.

4.6.6 Maximum (Max) Fill Rates (Capstans)

The 1-sec and 20-sec fill rates for the two suit sizes are compared in Table 43.

TABLE 43. CAPSTAN FLOW RATES FOR THE PNEUMATIC LEVER ANTI-G SUIT

SUIT VOL	F_M	$\bar{F}_M$	F_M	$\bar{F}_M$
	[1 sec]		[20 sec]	
Mid	39.7	37.0	21.9	2.5
Max	51.4	39.0	21.2	2.7

F_M = the peak flow measured during the 5 runs.

$\bar{F}_M$ = the average maximum flow.

4.6.7 Flow Requirements (Capstans)

To fill the Pneumatic Lever Suit capstans, in the required 2-sec time interval, necessitated a steady flow of 17.7 SCFM and a peak flow of 37 SCFM. Therefore, any valve used with the capstans should be able to deliver these flow rates for G-onset rates approaching 4 G/sec.

4.6.8 Normalized Parameters (Capstans)

The normalized force gage and suit-pressure profiles are not very tight (e.g., they are scattered at all fill and bleed rates). This finding indicates that the capstans do not fill and bleed as a unit, with bladders lagging the input suit pressure by a considerable amount. In fact, portions of the capstans appear to be evacuated, while other portions are only starting to evacuate. (This phenomenon is discussed in section 6.6.)

4.6.9 G-Force Effects

The Pneumatic Lever Suit was run through identical 1-sec and 20-sec fill and bleed tests under static conditions, 2 G and 10 G. Tables 44, 45, 46, and 47 contain the maximum normalized difference for the respective parameters under G and static conditions. Examination of graphs of the cases resulting in the greatest differences (refer to Appendix M) reveals that these generally occur:

1) at flow shut-off point,

2) during the first ¼ sec of data, or

3) at discontinuities in the curves.

Examination of the following tables, and associated plots, indicates that there is no significant G-effect upon the performance of the Pneumatic Lever Suit. All deviations between static and G-stressed conditions are less than 0.1 for the bladder and less than 0.3 for the Capstans, and are probably not physiologically significant. It is significant that the only deviation over 0.2 occurred during the 1-sec fill in the right thigh of the Capstans, and is probably due: to suit-skin friction impeding the application or release of pressure on the force sensor; or to discontinuities in the Capstan curves, which occur in this suit only.

TABLE 44. THE 1-SEC AND 20-SEC FILL-RATE TES ᴴE PNEUMATIC LEVER [CAPSTAN] ANTI-G SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
[FILL RATE = 1 SEC; G-FORCE = 2 G_z]						
MID	0.07062	0.03392	0.0	0.0	0.0	0.0
[FILL RATE = 1 SEC; G-FORCE = 10 G_z]						
MID	0.06996	0.06829	0.0	0.0	0.0	0.0
[FILL RATE = 20 SEC; G-FORCE = 2 G_z]						
MID	0.00503	0.01135	0.0	0.0	0.0	0.0
[FILL RATE = 20 SEC; G-FORCE = 10 G_z]						
MID	0.03863	0.04058	0.0	0.0	0.0	0.0

TABLE 45. THE 20-SEC AND 1-SEC EXHAUST-RATE TESTS OF THE PNEUMATIC LEVER [CAPSTAN] ANTI-G SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
[EXHAUST RATE = 20 SEC; G-FORCE = 2 G_z]						
MID	0.01305	0.08246	0.0	0.0	0.0	0.0
[EXHAUST RATE = 20 SEC; G-FORCE = 10 G_z]						
MID	0.02218	0.02714	0.0	0.0	0.0	0.0
[EXHAUST RATE = 1 SEC; G-FORCE = 2 G_z]						
MID	0.02633	0.01311	0.0	0.0	0.0	0.0
[EXHAUST RATE = 1 SEC; G-FORCE = 10 G_z]						
MID	0.02509	0.02587	0.0	0.0	0.0	0.0

TABLE 46. THE 1-SEC FILL-RATE TESTS OF THE PNEUMATIC LEVER [CAPSTAN] ANTI-G SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
[FILL RATE = 1 SEC; G-FORCE = 2 G_z]						
MID	0.04774	0.0	0.22425	0.17909	0.18542	0.18902
[FILL RATE = 1 SEC; G-FORCE = 10 G_z]						
MID	0.0	0.0	0.0	0.0	0.0	0.0
[FILL RATE = 1 SEC; G-FORCE = 2 G_z]						
MID	0.01651	0.0	0.05130	0.03345	0.03308	0.07830
[FILL RATE = 1 SEC; G-FORCE = 10 G_z]						
MID	0.03566	0.0	0.07800	0.07098	0.17275	0.10494

TABLE 47. THE 20-SEC EXHAUST-RATE TESTS OF THE PNEUMATIC LEVER [CAPSTAN] ANTI-G SUIT

SUIT VOLUME	SUIT PRESSURE	BLADDER	RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
[EXHAUST RATE = 20 SEC; G-FORCE = 2 G_Z]						
MID	0.01079	010	0.01359	0.02557	0.01469	0.02234
[EXHAUST RATE = 20 SEC; G-FORCE = 10 G_Z]						
MID	0.04620	0.0	0.08585	0.08130	0.06500	0.08593
[EXHAUST RATE = 20 SEC; G-FORCE = 2 G_Z]						
MID	0.00008	0.0	0.00071	0.00080	0.00013	0.00131
[EXHAUST RATE = 20 SEC; G-FORCE = 10 G_Z]						
MID	0.00121	0.0	0.00047	0.00144	0.00179	0.00190

5. ANTI-G PROTECTIVE SYSTEM FIELD-TEST PROCEDURES

The TEHG contractor has reviewed existing field-test procedures and has recommended improvements in several areas.

5.1 Anti-G Suit Field-Test Procedures

5.1.1 Introduction

During the TEHG contract, existing anti-G suit field-test procedures were examined and compared to those of the TEHG anti-G suit tests. Several areas were found for improvement in the existing field-test procedures. It should be considered, however, that the need for modifying or extending the present procedures--or the addition of tests to prevent specific types of failures--might best be substantiated by a thorough review of the history of anti-G suit failures. Such a study was beyond the scope of the TEHG contract; and therefore the proposed additional anti-G suit field-tests have been based on an engineering failure mode evaluation of anti-G suits.

Anti-G suits are presently being examined in the field, on a periodic basis, in two ways: first, through visual inspection by life-support technicians; and second, for leak rate at 5 psig.

5.1.2 Anti-G Suit Visual Inspection Procedures

Anti-G suits are presently being visually inspected every 120 days for holes, tears, loose or faulty zippers or fasteners, broken or worn lacings, faulty hose connections, contamination, or obvious signs of physical damage or excessive wear. The criteria for these judgments are somewhat subjective and may vary slightly from one installation to another; but the inspections are performed by life-support technicians whose training and expertise best enable them to evaluate the anti-G suit condition. The TEHG contractor has no recommendations for modifications to existing USAF anti-G suit visual inspection procedures.

5.1.3 Existing Anti-G Suit Test Procedures

Present anti-G suit periodic test procedures in use at USAF field installations are limited to the inflation of the suit to a specified pressure level and to the monitoring of the pressure decay over a specified time period. Existing procedures specifying the anti-G suit tests are quite brief, and leave much of the test methodology and interpretation to the discretion of the testing agency. Neither the rate nor the method of anti-G suit pressurization is specified, and pressure sources vary from hand pumps to regulated high-pressure bottles. Instrumentation is not standardized, and numerous types of gages are in use. Anti-G suit configuration during testing is not specified, and varies--from "open and

lying flat," to being worn by an aircrew member during the test. The acceptable anti-G suit leak rate is presently specified as "less than 1 psig drop from 5 psig in the suit at the start of testing in one minute." At some installations this test has been waived by USAF Air Training Command (ATC) to "1 psig drop from 5 psig in 20 sec." Anti-G suits with leak rates in excess of these specifications are condemned.

These test procedures do not account for the initial volume of the suit in making leak rate considerations. Initial suit volume has a significant effect on leak rate; for instance, a British Mini Anti-G Suit, leaking from 5 to 4 psig in 20 sec, would have an average leak rate flow of 0.079 SCFM--whereas an LBFP Anti-G Suit, with the same pressure drop in the same time, would have an average leak flow rate of 0.314 SCFM (or about four times higher than the British Mini). (NOTE: These flow rate calculations, based on suit volumes with the suit mounted on a mannequin, would be slightly higher for an unmounted suit.) The same effect would be noted between testing a "small-regular" and a "large-long" anti-G suit of the same basic type. The result of this situation is that a smaller anti-G suit might fail the existing test and be condemned, while a larger suit with a much larger leak (puncture, or hole) might pass the test and be returned to service.

Testing during the TEHG program has shown that leakage, per se, in an anti-G suit does not have a significant effect on performance, for any of the anti-G valves tested could easily maintain anti-G suit pressures up to 10 psig, even with anti-G suit leak rates far in excess of those now deemed acceptable. For example, a USAF CSU 13A/P medium-regular anti-G suit, leaking from 5 to 4 psig in 1 min, would be losing air at the rate of 0.040 SCFM; or, at the 20-sec interval, the suit would be losing air at 0.120 SCFM. During TEHG testing of the ALAR 8400A anti-G valve, leak rates as high as 3.0 SCFM were introduced into a CSU 13A/P anti-G suit at pressures up to 8 psig to test the anti-G valve sensitivity to pressure hysteresis. Identical tests were run using the British VAG 110-007 anti-G valve. The results of these tests were completely negative; that is, no effect was discernible on suit pressure vs. G_Z as a result of suit leaks of up to 3.0 SCFM. In other words, the flow capabilities of these valves at the test pressures exceed the suit leak rate. From these test results, the necessity of condemning an anti-G suit, leaking at a rate of 0.040 SCFM, seems questionable from an operational or performance point of view. However, leakage could be considered an indication of an impending suit failure. Sufficient data are not available to establish any statistical correlation between anti-G suit leakage and subsequent failure; for actual suit test data are not presently recorded--only whether or not the suit met the test criteria. Also (as already mentioned), present anti-G suit test procedures do not provide a reliable indication of suit leak size. Because the rupture of an anti-G suit under high G_Z would present a substantial hazard to the aircrewman, a test to provide a reliable indication of an impending suit failure should be considered.

Present anti-G suit test procedures are designed to expose only suit-pressure loss. Restrictions to air flow into the suit, which could

so impede pressurization of the suit that the anti-G suit-valve system could not maintain the proper inflation schedule under a rapid G_z onset rate situation, also represent a potential failure mode of anti-G suits. Such restrictions could be caused by foreign matter in the inlet hose, by the inlet hose connector, by loose fabric in the inlet hose or bladder interconnecting lines, by twisted or pinched lines, or by various other factors.

5.1.4 Proposed Anti-G Suit Field-Test Procedures

The following proposed procedures are based on the experience gained in the conduct and results of anti-G suit-valve testing during the TEHG contract. Each of the proposed tests has been performed by the TEHG contractor during the contract, and samples of resulting data are provided to illustrate the form of the proposed field-test data. The sample curves are based on a limited number of tests due to the limited availability of sample anti-G suits. Before precise acceptance limits are defined, it would be necessary to obtain a statistically significant number (ten, randomly selected, would be minimum) of anti-G suits, of each type and size to be field tested, to establish a high confidence level of mean values and standard deviations between suits.

The proposed anti-G suit field tests have been designed to incorporate a proof pressure check, a flow impedance test, and a suit leak test into two simple sequential tests which can be readily accomplished by an automatic checkout system. These tests and the related acceptance criteria will account for variations in volume, hose impedance, and stretch between the various types and sizes of suits to be tested. Further, the proposed tests provide checks on the three main failure modes of anti-G suits (i.e., bursting, restricted air flow, and high leakage rate).

5.1.5 Anti-G Suit Test Configuration

In order to provide uniformity and to assure proper conformity of the test results to required performance curves, all anti-G suits must be configured to an identical condition prior to and during the tests.

The anti-G suit field test will be accomplished after the suit has been visually inspected and found acceptable. The anti-G suit under test will be placed flat on a suitable surface, with the front of the suit facing up. The inlet hose of the suit will be fully outstretched, and the hose and bladder interconnecting lines will be examined to insure that no kinks or twists are in the lines. All suit zippers will be closed, and fasteners will be connected. All lacings will be installed, tied off, and stowed properly.

5.1.6 Anti-G Suit Proof Pressure and Stretch Test

The purpose of this test is twofold: (1) The suit is pressurized above the maximum operational level to provide a proof pressure test for possible hose or bladder rupture. (2) Because TEHG testing has shown that the volume of a suit changes significantly on the first pressurization after a period of storage, this test will provide a common volume condition for all suits of the same type and size, regardless of their frequency of usage.

The suit (configured as stated in section 5.1.5) will be pressurized to 12.0 psig. To assure that all of the suit bladders are pressurized evenly, flow into the suit should be so regulated that 30 +/- 5 sec are required for the suit pressure to reach 12.0 psig. Upon reaching 12.0 psig, air flow to the suit should be terminated and the suit allowed to remain under pressure for 1 min. (NOTE: Suit-pressure drop during this period is not significant and need not be monitored.)

5.1.7 Anti-G Suit Flow Impedance and Leak Test

The purpose of this test is to establish both the air flow impedance and the leak rate characteristics of the anti-G suit. The air flow impedance will be tested in both the fill and exhaust directions.

This test would probably be best implemented by the use of an automatic control and recording device, because a manual system would probably introduce an unacceptable amount of variation in test data.

To permit proper evaluation of test data, a strip-chart recorder should be used to plot anti-G suit pressure vs. time. The time scale of the recorder must be capable of resolving 0.25 sec.

The anti-G suit will be configured as at the end of the first test with approximately 10-psig suit pressure. If necessary, the suit pressure will be adjusted to 10 ± 0.2 psig. The suit pressure will be exhausted to ambient pressure through a large valve for 2.0 sec, at which time the valve will be closed. Suit pressure will be monitored for 1 min after the valve is closed. Anti-G suit pressure shall remain at 1 psig or less for 1 min, and each of the bladders will be "soft" (indicating a very low pressure level).

The anti-G suit will be evacuated with a mild vacuum (approximately 15 in. of mercury). Before the next tests are begun, the suit will be examined to assure that all bladders, interconnecting lines, etc., are completely evacuated.

The anti-G suit will be pressurized to 10 ± 0.2 psig in 3 sec. The transducer recording suit pressure will be connected to the system just upstream from the anti-G suit fill connector, so that the pressure being recorded will represent the pressure at the suit inlet connector. For

rapid fill rates such as this test, after initially indicating 10 psig, the suit pressure will immediately (within 0.125 sec) fall back to some lower value as the pressure equalizes throughout the suit.

Anti-G suit-pressure levels will be recorded at the 1- and 2-min levels after the initial 3-sec inflation of the suit. After the suit pressure at the 2-min point has been recorded, the suit may be vented and equipment secured from test. Figures 17, 18, and 19 show typical 3-sec inflation curves, respectively, for the following anti-G suits (medium-regular size): the CSU 12/P; the CSU 13A/P; and the CSU 15/P. The 1- and 2-min suit-pressure levels are also shown. Note that, on these curves, the suit pressure rises rapidly for a short time ($\leq$0.25 sec), levels at a nearly constant pressure for 1.5 to 2.0 sec, and then rises rapidly to 10 psig. The constant pressure level on the curve is a significant data point for the anti-G suit field-test, as this level represents the relative flow impedance of the suit fill hose and connector. An anti-G suit acceptance criterion will be stated giving an acceptable tolerance on the "fill flow impedance" characteristic of each type of suit to be tested. It will also be noted (from the information just given) that, after initially reaching the 10-psig pressure level, the pressure falls rapidly ($\leq$0.125 sec) to some point at which the curve suddenly flattens. This point, which also provides a data point for anti-G suit acceptance criteria, represents the internal flow impedance of the anti-G suit under test. As a matter of interest (Figs. 17-19), note the much improved flow capabilities both in the fill hose and internal flow of the CSU 13A/P and CSU 15/P suits, as compared with those of the CSU 12/P. The point at the 1-min level includes suit-pressure loss not only from pressure equalization and suit leakage, but also from the effect of the anti-G suit having stretched through the sudden application of pressure. The effect of pressure on anti-G suit volume (suit stretch) is evident in Figures 20-22, concerning the respective volumes of the CSU 12/P, CSU 13A/P, and CSU 15/P anti-G suits (medium-regular size) as a function of pressure. The pressure loss from the 1-min point to the 2-min point, a period in which the suit has stabilized, is due almost entirely to suit leakage. The allowable pressure drop between the 1- and 2-min levels will specify the criterion for the anti-G suit leak rate.

5.1.8 Anti-G Suit Field-Test Acceptance Criteria

As already explained (in section 5 of this volume), suit volume must be a consideration in calculating suit leakage rates from pressure drop measurements. As a result of this characteristic and other differing characteristics in various types of anti-G suits, it will be necessary to provide an acceptance criteria number for each type and size of anti-G suit to be tested.

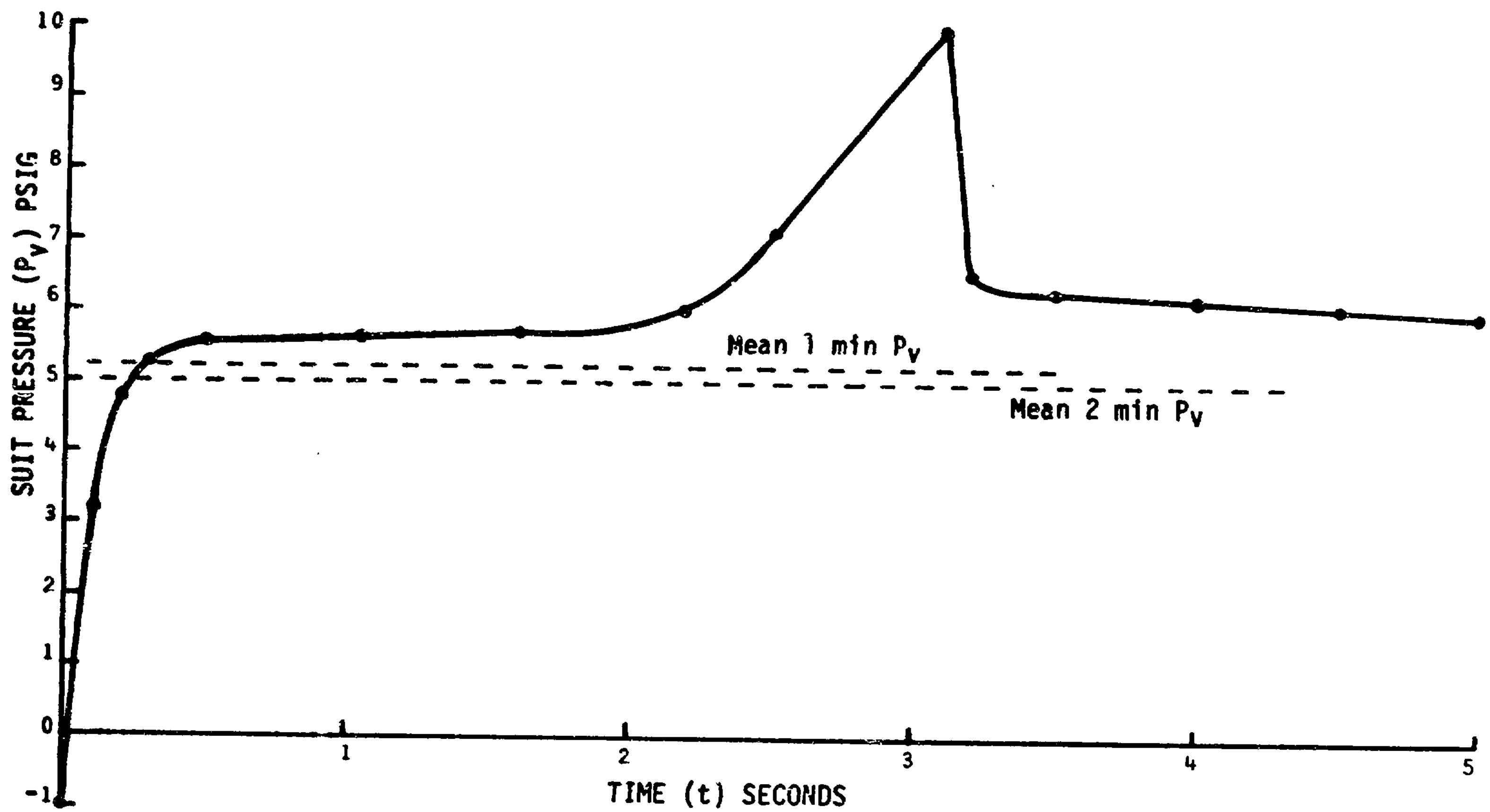

Figure 17. The typical 3-sec inflation curves for the CSU-12/P anti-G suit (medium-regular size).

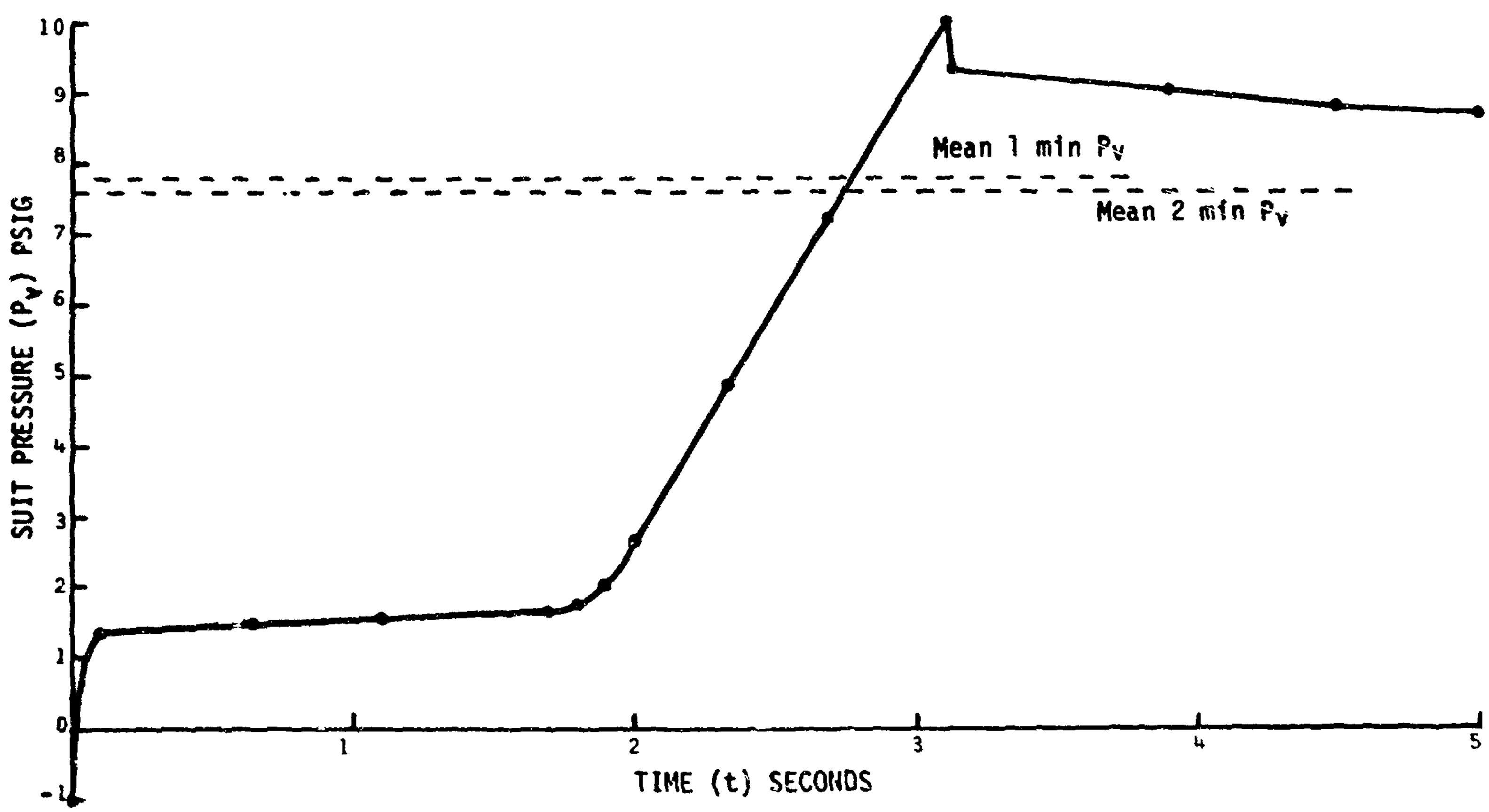

Figure 18. *The typical 3-sec inflation curves for the* CSU-13A/P anti-G suit (*medium-regular size*).

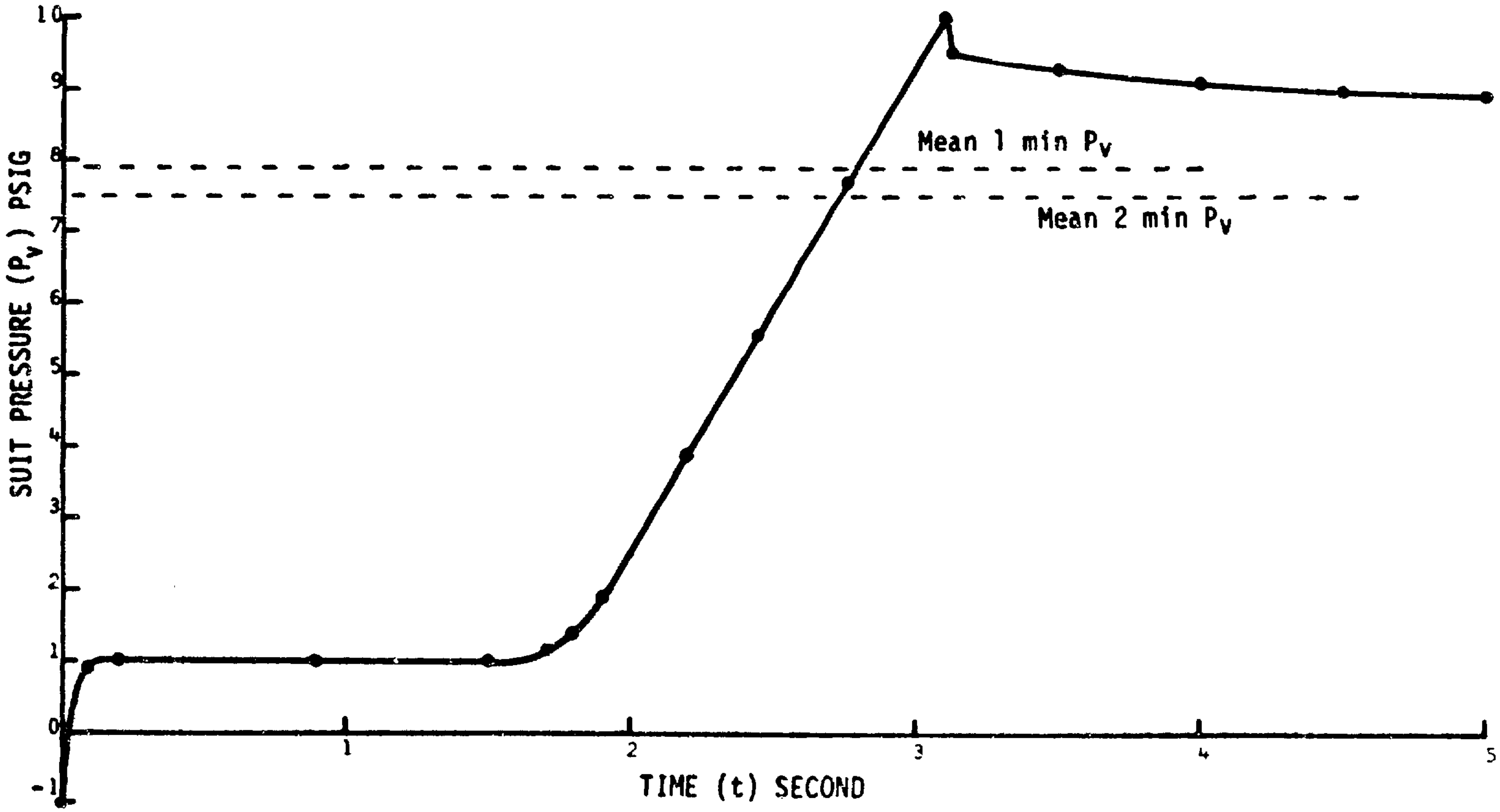

Figure 19. The typical 3-sec inflation curves for the <u>CSU-15/P</u> anti-G suit (medium-regular size)

The TEHG contractor tested numerous anti-G suits to establish the proposed test procedures and limits. However, sufficient quantities of the various suits were not available, thus precluding a statistical sample large enough to set definite limits. Hence, it is suggested that a minimum of 10 randomly selected anti-G suits, of each type and size being considered, be field-tested for volume to provide such a statistical data base. Although this task appear large, it could be readily accomplished using test equipment already developed during the TEHG program.

5.1.8.1 Anti-G Suit Leak Rate Acceptance Criteria

Mean anti-G suit standard air volumes vs. suit pressure for the CSU 12/P, CSU 13 A/P, and CSU 15/P suits (medium-regular size) are shown in Figures 20, 21, and 22, respectively. This method of display is of particular value in calculating suit leak flow rates, since the volume of air lost from the suit in dropping from one suit pressure to another can be read directly from the curve. If temperature is assumed to remain constant during this change, the leak flow rate is given by:

$$\text{Suit Leak Rate (SCFM)} = \frac{SAV_{@}P_i - SAV_{@}P_f}{\text{time in minutes}} (3.531\times10^{-2})$$

[NOTE: The factor 3.531×10^{-2} is for the conversion of liters to cubic feet.]

The maximum mean anti-G suit leak rate which is accepted under existing criteria (from 5 to 4 psig in 20 sec) is about 0.114 SCFM, computed from the average allowable for CSU 12/P, CSU 13A/P, and CSU 15/P medium-regular suits. Since the anti-G suit leak rates of this order of magnitude are not operationally significant (refer to section 5.1.3) and since the proposed test includes a proof pressure test, it is recommended that this allowable rate be increased to 0.25 SCFM. Suit leak rates of this magnitude are already allowable under existing specifications for the largest anti-G suits, but represent a relaxation of leak tolerances for most of the anti-G suits in USAF inventory. It is further recommended that, if the proposed anti-G suit field-test program is implemented, a subsequent study of anti-G suit failure incidence be made to examine the adequacy of the specified anti-G suit allowable leak rate.

In terms of test data, the suit leak rate will be calculated from the suit-pressure readings taken at the 1- and 2-min test time intervals using the SAV vs. pressure curve provided for the particular suit under test.

5.1.8.2 Anti-G Suit Vent Flow Rate Acceptance Criterion

It is recommended that the anti-G suit vent flow acceptance criterion be stated as: Anti-G suit pressure will drop from 10 ± 0.2 psig to 1.0 psig or less, in 2 sec or less, when the suit hose connector is vented to atmosphere.

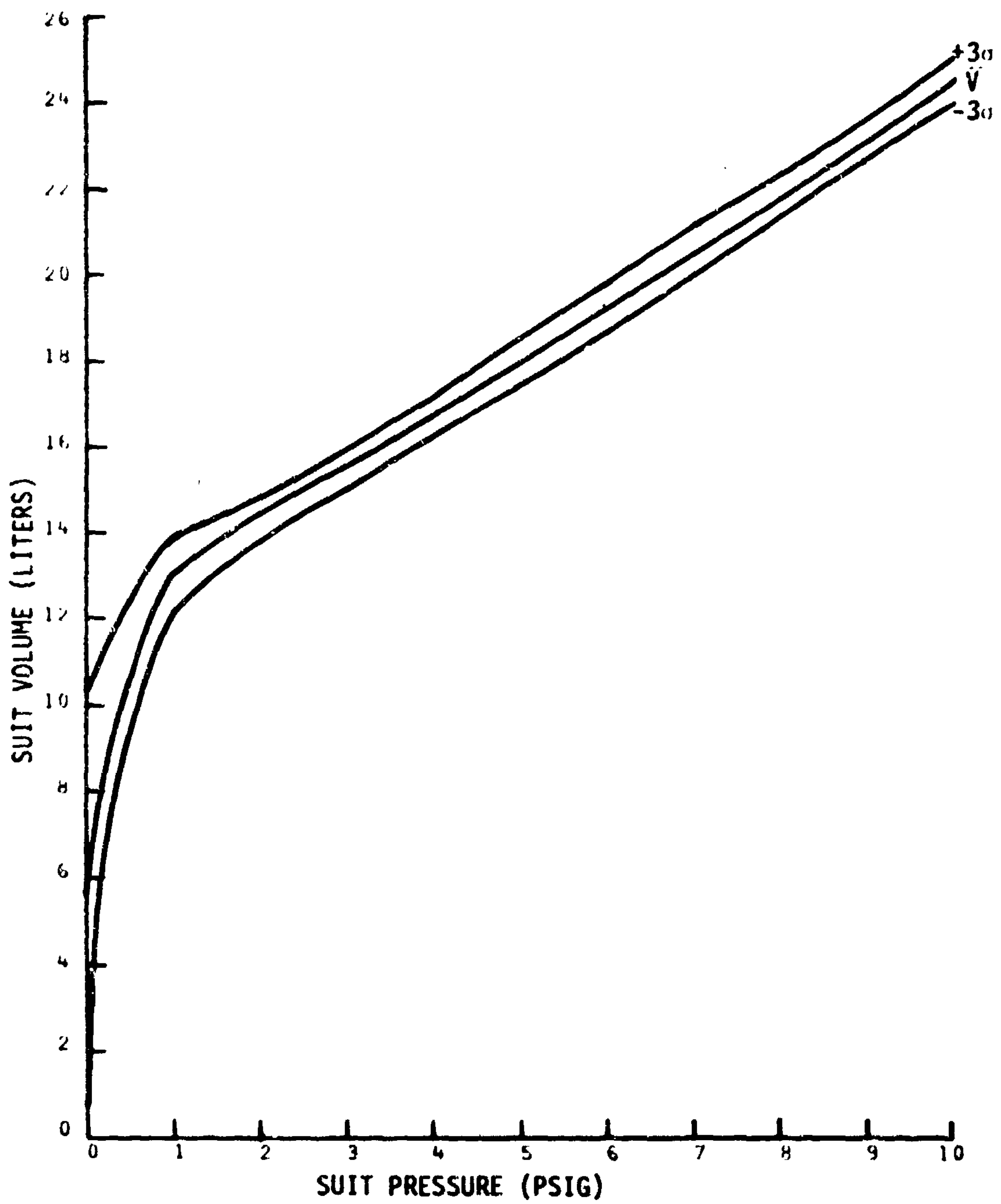

Figure 20. The effect of pressure on the volume (suit stretch) of the CSU-12/P anti-G suit (medium-regular size).

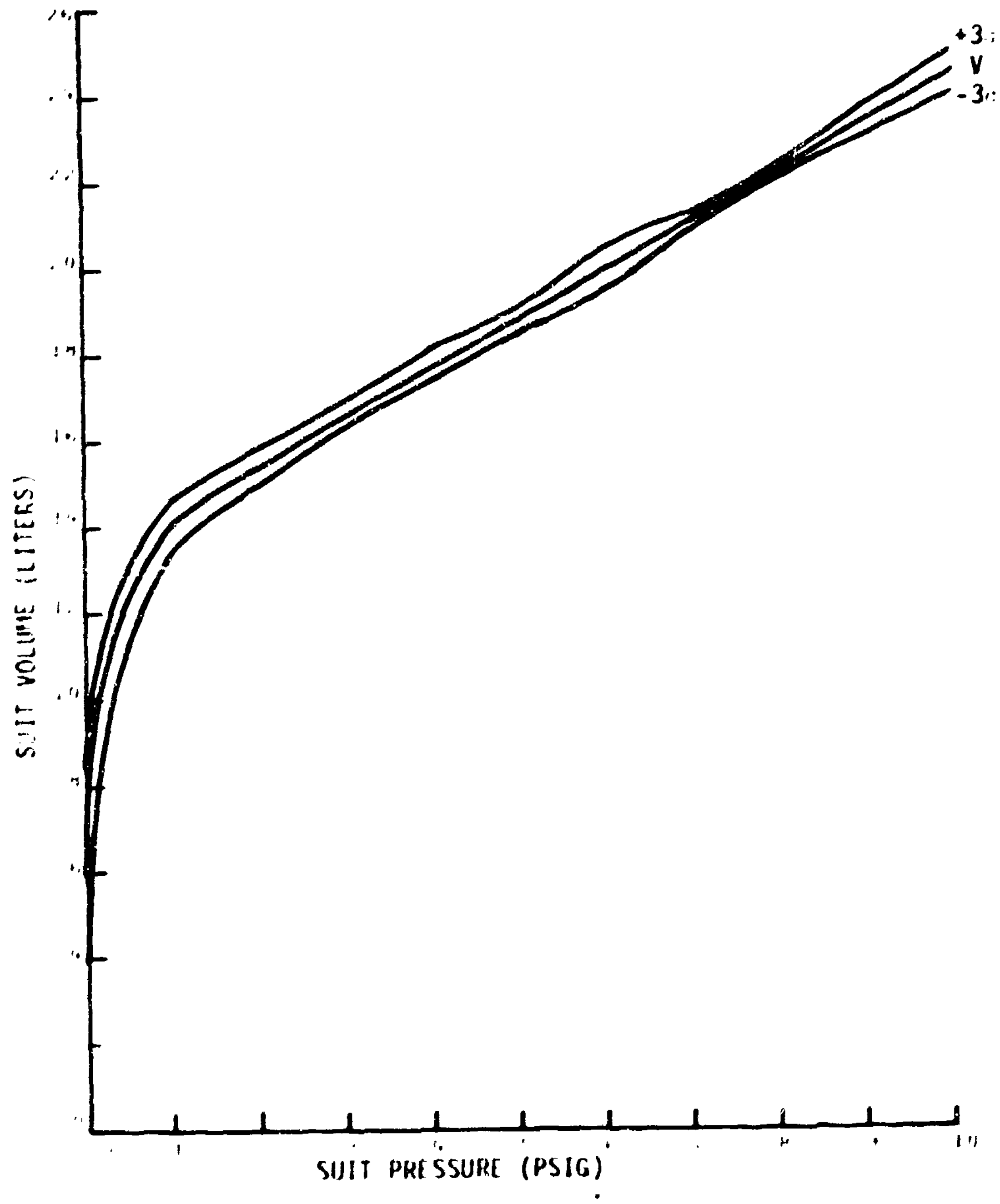

Figure 21. The effect of pressure on the volume (suit stretch) of the CSU-13A/P anti-G suit (medium-regular size).

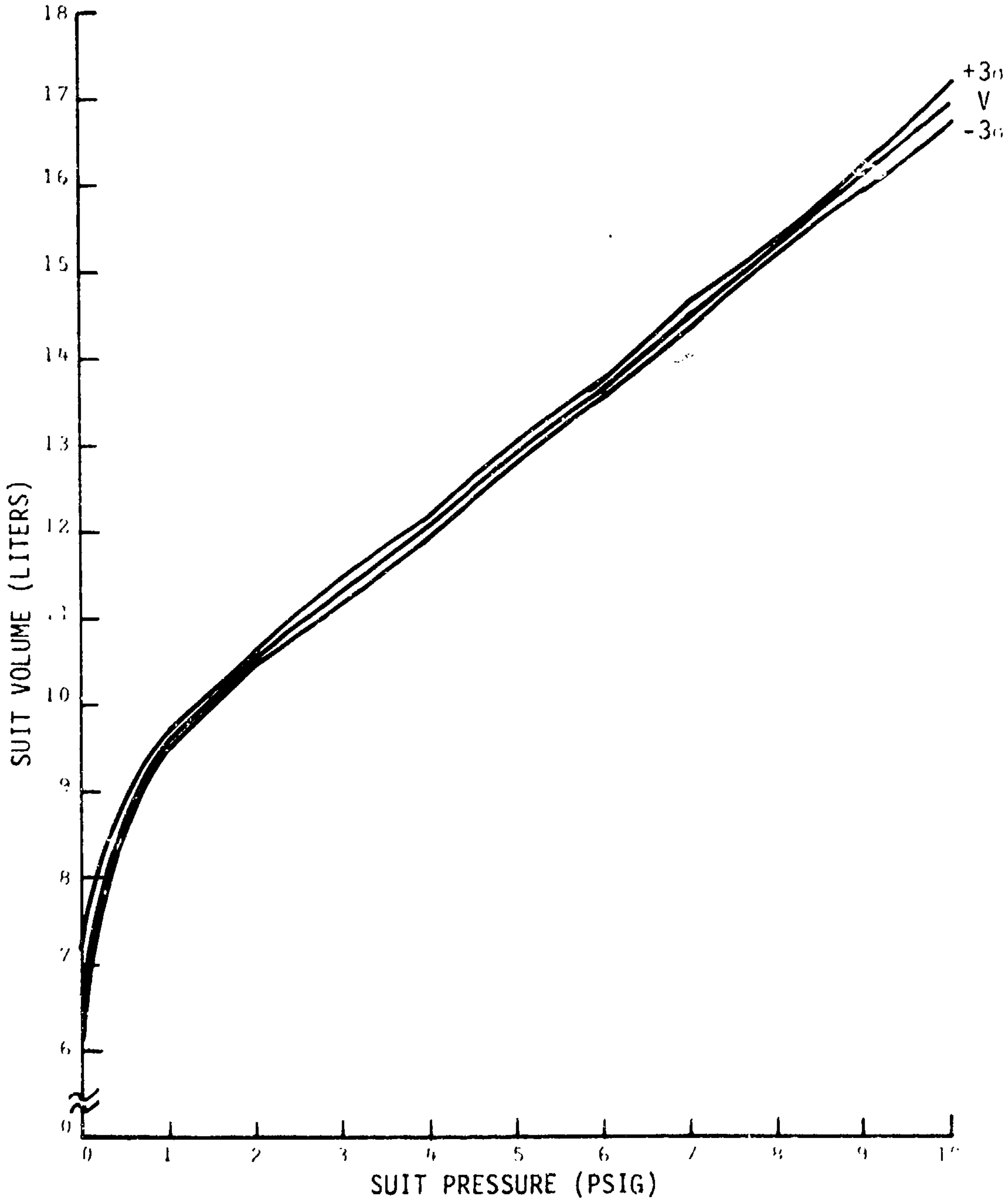

Figure 22. The effect of pressure on the volume (suit stretch) of the CSU-15/P anti-G suit (medium-regular size).

Although this requirement has not been verified on all sizes of all anti-G suits, it has been met or exceeded by all suits tested during the TEHG program, and therefore can be proposed with a high degree of confidence as a valid test criterion at this time.

5.1.8.3 Anti-G Suit Fill Flow Rate Acceptance Criteria

TEHG testing has shown that the anti-G suit fill flow rate varies widely between different suit types, and must therefore be stated individually for each suit type to be field tested. As stated earlier, sufficient numbers of anti-G suits were not available during the TEHG contract to establish a high confidence value for this parameter. Preliminary indications are that an increase of 1.0 psig or more in this parameter would show some flow impediment in the suit fill hose and would be cause for rejection of the suit. The magnitude of this parameter would be taken from the proposed field-test data as the average pressure value of the flat portion of the 3-sec inflation curve (Fig. 17 - 19) between approximately 0.25 sec and 1.75 sec.

5.1.8.4 Anti-G Suit Internal Flow Impedance Acceptance Criteria

The anti-G suit internal flow impedance is defined by the low point of the immediate pressure drop after reaching 10 psig on the 3-sec inflation curve (Figs. 17 - 19). TEHG anti-G suit testing has shown that this parameter varies from one type of suit to another, and probably to some extent between suit sizes of the same type. It would therefore be necessary to specify this parameter for each type, and perhaps size, of anti-G suit to be field tested. Again, the precise value of this acceptance criterion must await the testing of a statistically significant population of anti-G suits, but a preliminary estimate is that a decrease of 0.5 psig would be an indication of unacceptably high suit internal flow impedance.

5.1.8.5 Recommendations and Conclusions Concerning Anti-G Suit Field Tests

The following six points summarize the TEHG recommendations and conclusions for the field testing of anti-G suits:

1) A review of anti-G suit failures should be made to establish the most frequent types of failure and the adequacy of present field-test procedures.

2) Present anti-G suit visual examination procedures are adequate and need not be modified.

3) Present procedures should be changed to add more detail and equipment definition, to specify suit configuration during test procedure, to consider suit volume in making leak rate calculations, and to include tests for other anti-G suit failure modes.

4) Additional anti-G suit field-test procedures are proposed which define suit configuration for testing and include a proof pressure test, a suit exhaust flow test, a suit fill flow test, a suit internal flow impedance test, and a leak rate test.

5) Anti-G suit acceptance criteria are defined for each of the foregoing tests.

6) A statistically significant number of anti-G suits should be tested before exact acceptance criteria are defined.

5.2 Anti-G Valve Field-Test Procedure

5.2.1 Introduction

The existing field-test procedure for anti-G valves installed in aircraft is a simple press-to-test function check of the system. This test shows only that the valve will supply air pressure to the anti-G suit, and does not give any quantitative indication of performance, leak rate, etc. During the course of the TEHG contract, the procedures developed for testing anti-G valves have been reviewed for possible application to a field-test procedure. Also MIL-V-9370D, Aeronautical Standards Group (ASG), dated 18 October 1967--which specifies acceptance tests for anti-G valves--was reviewed to ascertain if any portion of these tests might be adaptable to an anti-G valve field-test procedure. [NOTE: MIL-V-9370D is available through the Aeronautical Standards Group, 8719 Colesville Road, Silver Spring, Md. 20910.]

As with the anti-G suits, no review was made of actual flight failures of anti-G valves to establish the adequacy of present testing or to establish the most common failure modes, as such a review was not within the scope of the TEHG contract.

5.2.2 Existing Anti-G Valve Tests

At the present time, anti-G valves are tested each 400 hr of flight time on the aircraft in which they are installed. This test consists of depressing the "press-to-test" button and listening to the resulting air flow from the valve. If, in the judgment of the technician performing the test, the valve performance is adequate--the valve is retained in service. If for any reason the anti-G valve is judged faulty--it is scrapped and replaced. Anti-G valves are listed as expendable items and are not usually repaired or overhauled.

Mil-V-9370D (ASG), the military specification governing automatic pressure-regulating valves for anti-G suits (anti-G valves), specifies a battery of tests for the acceptance of new anti-G valves. Although these tests are complete and precise, they specify the performance requirements for a new valve and may be too stringent for valves which have been in service. Mil-V-9370D specifies the allowable leak rate through a valve as 0.01 liters/min (3.53×10^{-4} CFM), with 300 psig applied to the inlet connector and valve pressure regulation, to be within ±2 in. Hg (0.01 psig) at stable pressure levels. As stated in section 5.1.3, TEHG testing has shown that leakage rates of up to 3.0 SCFM do not measurably affect anti-G protective system performance; and it is suspected that anti-G suit pressure variations of 0.01 psig would not have a physiologically significant effect on anti-G protection. It is assumed, therefore, that the anti-G valve acceptance criteria stated in Mil-V-9370D are based on a relative measure of anti-G valve precision and design requirements rather than on operational requirements.

5.2.3 Proposed Anti-G Valve Field Tests

Because of the variation in the mounting of anti-G valves in different types of aircraft, it is recommended that--in order to standardize test procedures--anti-G valves be removed from the aircraft for field testing.

It is also recommended that, to establish a quantitative measure of anti-G valve condition, three tests be performed on anti-G valves on a periodic basis.

As with the anti-G suit tests (refer section 5.1.7), it is suggested that a statistically significant number of anti-G valves be tested to establish precise acceptance criteria. A minimum of 10 randomly selected anti-G valves should be tested to define these parameters. Each valve should be selected from an aircraft with a minimum of 400-hr flight time on the valve.

(A) Anti-G Valve Field Leak Test: The anti-G valve under test is to be mounted on a suitable fixture with the G sensing axis positioned vertically. The inlet connector of the valve will be connected to a rigid container, 22 in.^{3} (361 cm^3) [an Emergency Oxygen Bottle of this volume is suggested]. The connecting line from bottle to the valve should be kept to a minimum length and size [an "AN (Army-Navy) type of steel braided high-pressure hose, 1/8 - 1/4 in. (3.2 - 6.4 mm) i.d., and about 18 in. (45.7 cm) in length, is suggested]. A suitable shut-off valve is to be connected to the opposite end of the bottle for pressure servicing. The bottle will be pressurized to 300 psig, measured by a suitable transducer connected to the bottle. Bottle pressure will be monitored for 5 min, with the pressure level being recorded each minute.

Allowable anti-G valve leak rate will be specified as a maximum pressure drop in the 5-min period. The precise value of this pressure drop cannot be specified until a sufficient number of valves have been tested (refer to section 5.2.3) to establish a statistical base.

(B) Anti-G Valve Relief Valve Field Test: The anti-G valve under test will be mounted on a fixture, as described in section 5.2.3 (A). The outlet of the anti-G valve will be connected to a tank with a volume of at least 1 liter. The tank will be connected to a suitable pressure gage or transducer with a range of at least 0 - 15 psig. The inlet of the anti-G valve will be connected to a regulated 300-psig pressure source. The "press-to-test" button will be depressed as far as possible. The relief valve will be observed to open at a pressure between 8.5 psig and 11.0 psig. The "press-to-test" button will be held fully depressed for 10 sec, and the pressure in the tank shall not exceed 11.0 psig.

(C) Anti-G Valve Response Field Test: The anti-G valve under test will be mounted on a fixture, as described in section 5.2.3 (A), and the inlet will be connected to a regulated 125-psig pressure source. The outlet of the valve will be connected to a flexible container with a volume of approximately 10 liters. (An anti-G suit is suggested.) A pressure gage or transducer with a range of at least 0 - 15 psig will be connected to the valve output line. Weights simulating 2, 4, 6, 8, and 10 G will be successively placed in the "press-to-test" button, and then will be successively removed in reverse order. Pressure readings taken at each G level will be within the following limits:

G Level	Pressure (psig)
2	0.00 - 1.10
4	2.90 - 4.19
6	5.80 - 7.29
8	8.70 - 10.38
10	8.70 - 11.00

The time for the pressure to stabilize at G level, after the weight has been added or removed, shall not exceed 5 sec.

5.2.4 Conclusions Concerning Anti-G Valve Field Tests

Although the suggested field tests of anti-G valves are more time consuming than present test procedures and will require some additional equipment, the performance of the proposed tests at 400-hr intervals will provide a significant improvement in the quantitative evaluation of anti-G valve condition.

6. SUPPLEMENTAL PNEUMATIC LEVER ANTI-G SUIT EVALUATION

Additional tests were performed under Contract Extension P00006 to the basic TEHG contract. The purpose of these tests was to measure quantitatively the forces applied to various surface areas of a mannequin by the USAF Capstan Anti-G suit exposed to various levels of acceleration (G_Z) and to varying onset rates. The tests also indicated such factors as lead or lag time between different Capstan bladder inflations and deflations, and between abdominal bladder and Capstan bladder inflations and deflations.

6.1 Description of Test

The following tests evaluated, under dynamic conditions on the Human Centrifuge at USAFSAM, the performance of the USAF Pneumatic Lever (Capstan) anti-G suit (P/N 12392G-03KXAZO, from David Clark Co., Inc., 360 Franklin St., Worchester, Mass. 01613). The abdominal bladder of the suit was pressurized by a standard ALAR 8400 "A" anti-G valve. The Capstan section of the suit was pressurized by an ALAR 8524 "special" anti-G valve.

6.2 Description of Test Setup

A fiberglass mannequin was fitted with a USAF Capstan anti-G suit, P/N 12392G-03KXAZO (medium-regular size). The suit was fitted to the mannequin with a 4 to 1 (limb diameter to capstan diameter) ratio at the calves, and an approximate 6 to 1 ratio at the thighs. The waist and the abdominal bladder were adjusted to a proper fit. The mannequin was equipped with force button strain-gages--on the abdomen, lumbosacral region of the back, left and right thighs, and left calf--which measured the force (applied by the suit) normal to the mannequin at these points.

An instrumentation test table was mounted in the gondola. The ALAR 8524 special anti-G valve was so mounted on this table as to be alined with the gondola accelerometer. Also mounted on the test table

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EDITOR'S NOTE: For detailed information on the subject of relevant valves, the reader is referred to Volume II (of the TEHG series), entitled: ANTI-G VALVES (SAM-TR-78-11).

were: a flow transducer (0 - 60 SCFM); a Giannini pressure transducer (0 - 30 psia); a Teledyne pressure transducer (0 - 500 psig); a CIC pressure transducer (0 - 250 psig); and an ASCO solenoid valve (ASCO = Automatic Switch Co., Florham Park, N.J.). [Addresses of the other companies are given in section 6.3, as footnote to tabulated material]. The instrumentation configuration is shown in Figure 23 (refer to p. 117).

A "K" bottle of compressed air and a pressure regulator also were mounted in the gondola. Air pressure from the K bottle was plumbed through the regulator to the flow transducer, with an intermediate tap for the CIC pressure transducer to monitor source pressure. Air pressure was plumbed from the flow transducer to the solenoid valve which was remotely actuated from the control console and was used to conserve air between tests. The solenoid valve was connected to the "inlet" of the ALAR 8524 Anti-G valve. The "outlet" of the ALAR 8524 was connected to the Capstan section of the suit, with an intermediate tap for the Teledyne pressure transducer at the suit connection to monitor capstan pressure.

The outlet of the existing gondola-mounted anti-G valve (ALAR 8400A) was connected to the suit abdominal bladder. The Giannini pressure transducer monitored the abdominal bladder connection at the suit connector. The existing gondola air-pressure source was used for the ALAR 8400A.

The signals from all of the instrumentation were transferred through the centrifuge slip rings to the control-room brush amplifiers; and data were recorded, both on brush charts and magnetic tape, for subsequent analysis.

6.3 Instrumentation and Parameters Monitored

On each shift, the transducers and data recording devices in these tests were calibrated prior to testing. Pressure transducers were calibrated at 0 psig and at a selected maximum pressure by using the Datametrics Pressure Calibration System. The flow meter system was calibrated by using the "internal" calibration check feature. The force transducers were calibrated at 0 lb (0 kg) and at 10 lb (4.536 kg) force, by using a special weight designed for this purpose.

The following information concerns the instrumentation used in these tests:

NO.	PARAMETER	ITEM	SOURCE*	MODEL	RANGE
1	Acceleration (G_z)	Accelerometer	Page	CA-19R-20G-1311	1-10 G
1	Source pressure	Pressure XDCR	CIC	3000	0-250 psig
1	Capstan pressure	Pressure XDCR	Teledyne	175	0-500 psig
1	Abdominal bladder pressure	Pressure XDCR	Giannini	451212-4	0-30 psia
1	Flow	Flow XDCR	Datametrics	800-LM	0-60 SCFM
5	Force	Force XDCR	Houston Scientific	1200-15C	0-15 lb (0-6.804 kg

*Company addresses: Page Engineering Co., 13035 Saticoy St., N. Hollywood, Calif.; CIC = Computer Instruments Corp., 92 Madison Ave., Hempstead, L.I., N.Y. 11550; Teledyne (now: Teledyne/Geotech), Box 28277, Dallas, Tex. 75228; Giannini, Pasadena, Calif.; Datametrics (A Subsidiary of ITE Imperial Corp.), 340 Fordham Rd., Wilmington, Mass. 01887; and Houston Scientific (The HSI Corporation), 4202 Directors Row, Houston, Tex. 77018.

XDCR = transducer

6.4 Test Protocol

Tests on the USAF Pneumatic Lever Anti-G Suit were conducted in the following phases (I - IV).

6.4.1 Phase I--Baseline Response

The purpose of this test was to establish the response of the suit to a very slow change in G_z and, therefore, to a very slow change in suit pressures. The test was set up (as already described in section 6.2) and the mannequin was mounted in the seat. Source pressure for the ALAR 8524 Capstan valve was set at 125 psig; and, for the ALAR 8400A abdominal bladder valve, at 80 psig. The centrifuge was accelerated, at a rate of 0.1 G/sec, from 1 G to 10 G. Data were recorded throughout this period, which comprised one "run." The centri-f[illegible], then decelerated, at the same rate, from 10 G to 1 G. Data [illegible]ecorded throughout this period and were documented as a separate [illegible]." A total of 10 runs (5 up and 5 down) were made to provide a [illegible]cistical data base.

6.4.2 Phase II--High Rate of Change Response

The purpose of these tests was to establish the response of the suit in a more rapidly changing G_Z field. The test setup described in section 6.2 was used. A total of 10 runs (5 up and 5 down) were made at each of three different onset rates (0.5, 1.0, and 1.5 G/sec).

6.4.3 Phase III--Simulated Aerial Combat Maneuver (SACM) Response

The purpose of this test was to establish the response of the suit to a rapidly varying G_Z field. (The test setup has been described in section 6.2.) The centrifuge was run through a SACM from 1 to 8 G. Data were taken during the run which was approximately 100 sec long. Three iterations of this test were made.

6.4.4 Phase IV--Suit-Mannequin Interface Pressure Calibration

In addition to the dynamic tests just listed, a series of static tests were performed. These tests established the relationship (scaling) between the force registered by the strain gages mounted on the mannequin and the actual suit-mannequin interface pressure. A water-filled bladder was inserted between the suit and the mannequin at a location near to, and circumferentially in line with, the strain gage being scaled.

> [NOTE: Prior to testing, the strain gages and associated recording equipment were calibrated from 0 to 10 lb (0 to 4.536 kg) force using a test weight.]

The water-filled bladder was connected to a calibrated pressure transducer, and the connecting line and transducer were bled free of air. Capstan pressure was increased from 0 to 50 psig; and capstan pressure, water-bladder pressure, and strain-gage force were recorded. A minimum of two water-bladder locations, usually diametrically opposed and in line with the strain gage. were tested for each strain-gage location.

6.5 Description of Data Curves

All data taken during the foregoing tests were recorded on brush charts and, with the exception of Phase IV, on magnetic tape for subsequent computer analysis and plotting. In all cases except Phase III, the mean values of the data taken on several runs were displayed. Data displayed for Phase III resulted from one "typical" run (selected from several runs) due to the inherent nonrepeatability of the ACM. Similar data were displayed on one graph, whenever possible, to facilitate comparison.

6.5.1 Definitions ("Key") for Symbols Used on Curves

The definitions (key) for the symbols used on Figures 24 - 50 are given in Table 48. The symbols are shown as data points on the curves in the respective figures.

6.5.2 Abdominal Bladder Pressure vs. Acceleration (Fig. 24)

In Figure 24, the curves present the pressure (psig) in the bladder vs. acceleration (G) for all four onset rates.

6.5.3 Capstan Pressure vs. Acceleration (Fig. 25)

In Figure 25, the curves present the pressure (psig) in the capstans vs. acceleration (G) for all four onset rates.

6.5.4 Abdominal and Back Interface Pressure vs. Bladder Pressure (Figs. 26 - 29)

In Figures 26 - 29, the curves show the pressure (psi) on the mannequin skin at the abdomen and lower back as a function of bladder pressure (psig). One curve is provided for each onset rate.

6.5.5 Calf and Thigh Interface Pressure vs. Capstan Pressure (Figs. 30 - 33)

In Figures 30 - 33, the curves show the pressure (psi) on the mannequin skin at the left and right thighs, and at the left calf, as a function of capstan pressure (psig). One curve is provided for each onset rate.

6.5.6 Abdominal and Back Interface Pressure vs. Bladder Pressure (Figs. 34 - 35)

In Figures 34 and 35, the curves show the pressure (psi) on the mannequin skin at the abdomen and lower back as a function of bladder pressure (psig). Curves for the abdomen and back are shown on separate charts which compare performance at 0.1 G/sec with that at 1.5 G/sec.

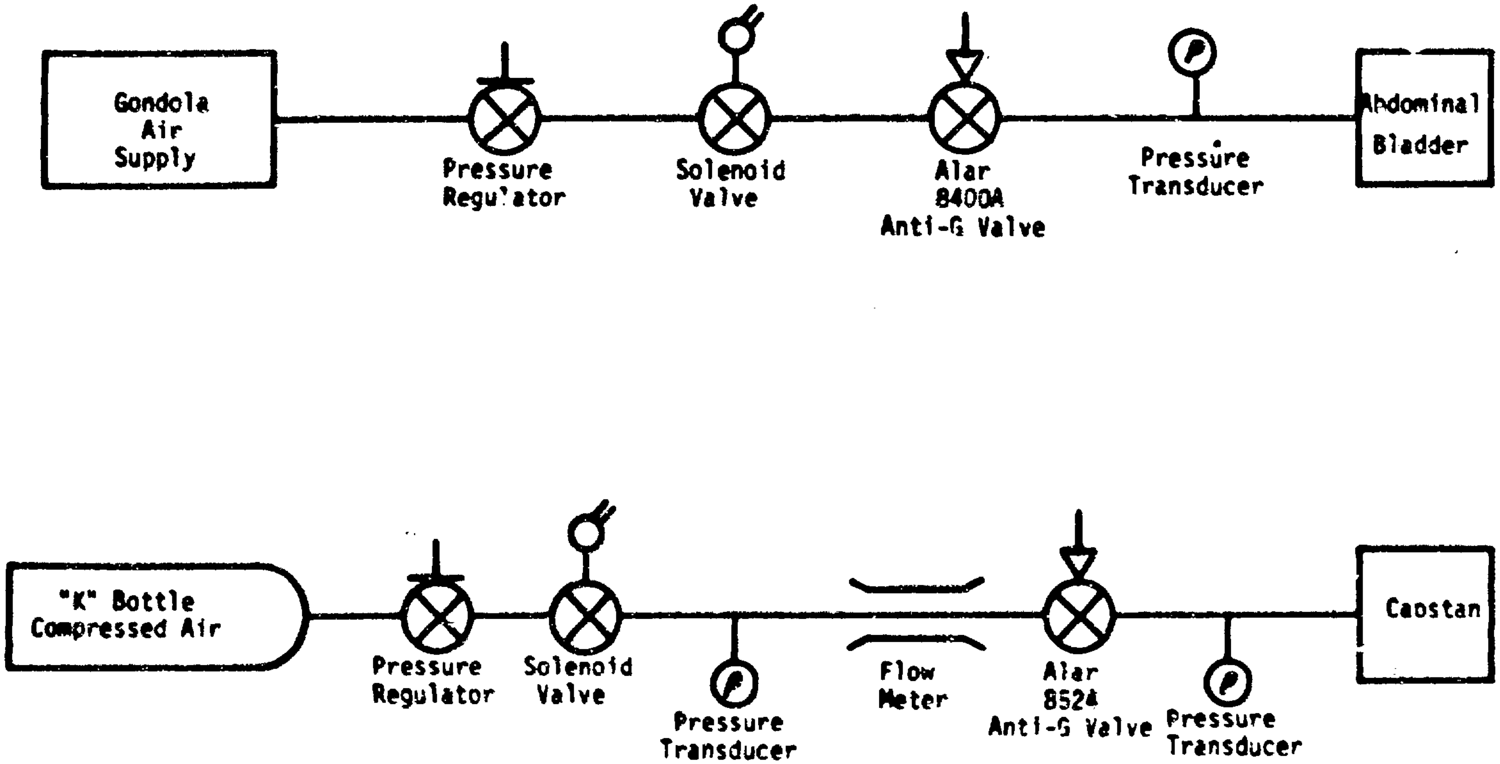

Figure 23. The test configurations for the USAF Pneumatic Lever (Capstan) Anti-G Suit, P/N 12392G-03KXAZ0 (medium-regular size, on mannequin).

TABLE 48. KEY TO SYMBOLS IN FIGURES 24 to 50
[Symbols are shown as data points on the curves. See footnote.]

1 - 0.1 G/sec onset rate

2 - 0.5 G/sec onset rate

3 - 1.0 G/sec onset rate

4 - 1/5 G/sec onset rate

* - Acceleration (G_z) used on ACM only

A - Abdominal interface pressure (P_I)

ACM - Aerial Combat Maneuver

B - Lower back interface pressure (P_I)

S - Suit pressure (capstan or bladder)

L - Left thigh interface pressure (P_I)

R - Right thigh interface pressure (P_I)

C - Left calf interface pressure (P_I)

I - Increasing G_z run

D - Decreasing G_z run

EDITOR'S NOTE: Due to the limitations of the technique initially used, these symbols are not always discernible on the respective curves. In such cases, however, the symbols are insignificant as compared with the close relationship obvious between the curves in each figure.

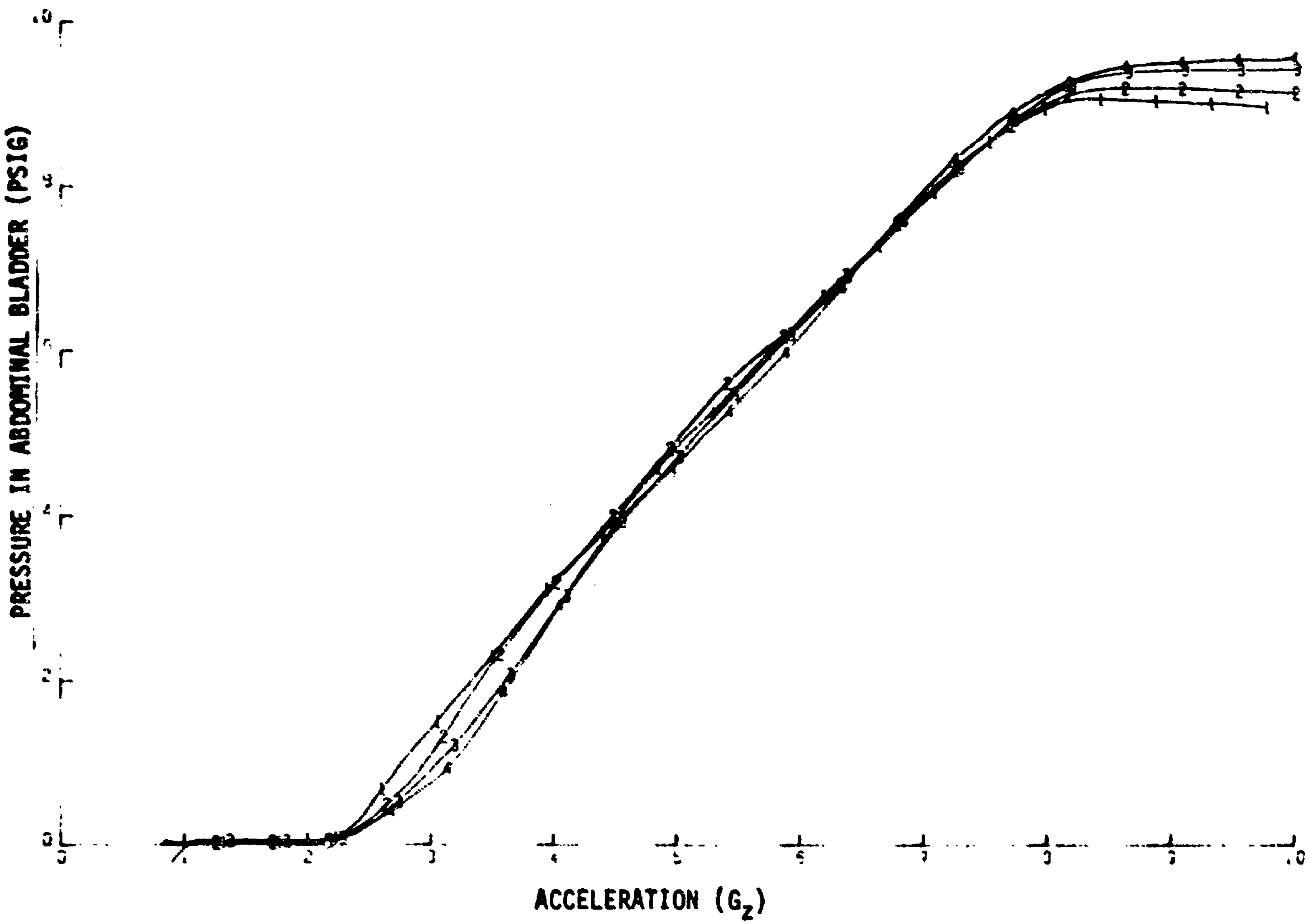

Figure 24. Abdominal bladder pressure vs. acceleration for four onset rates. [Curves are: 1, 2, 3, and 4. For "Key," refer to Table 48.]

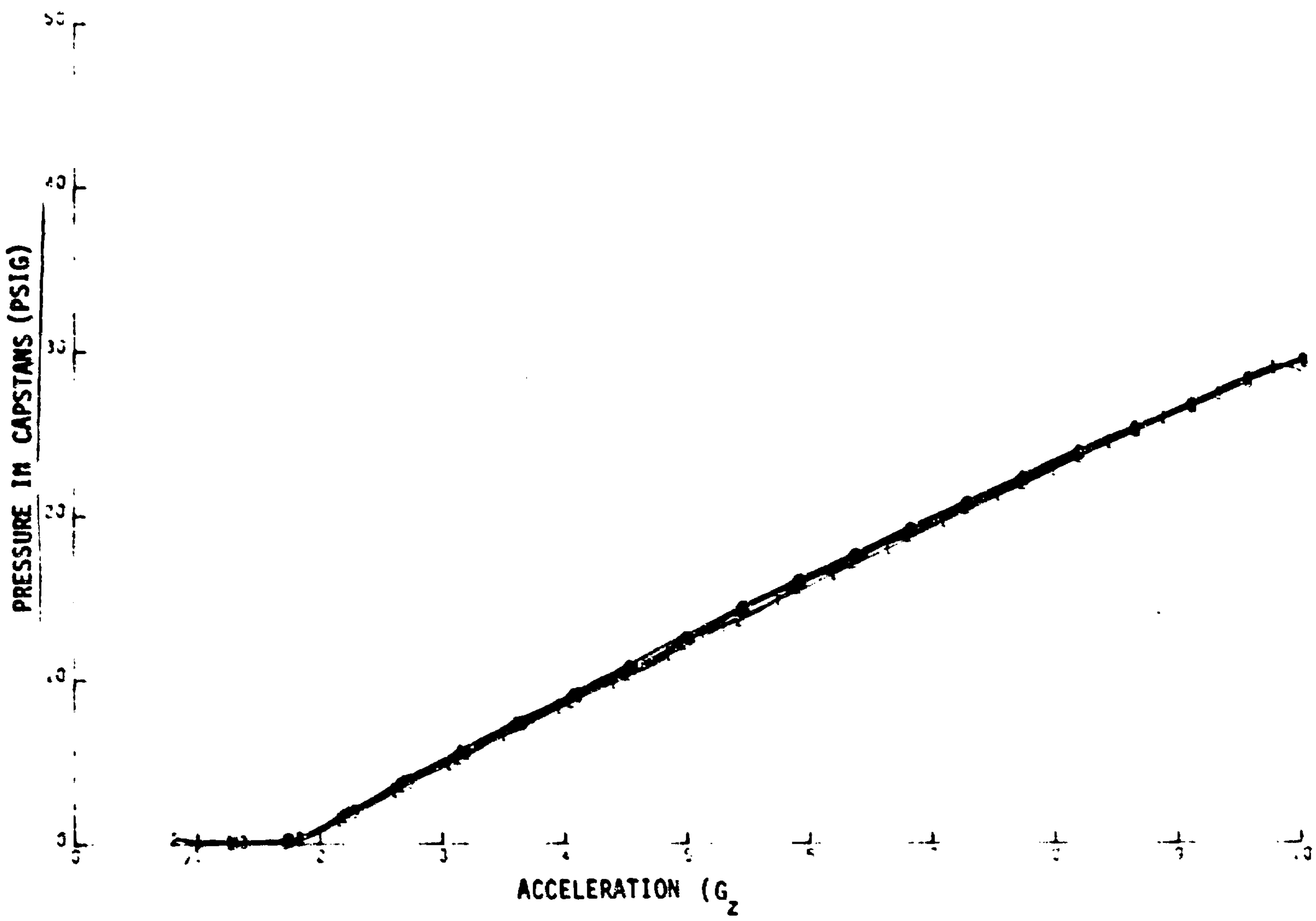

Figure 25. Capstan pressure vs. acceleration for four onset rates. [Curves are: 1, 2, 3, and 4. For "Key," refer to Table 48.]

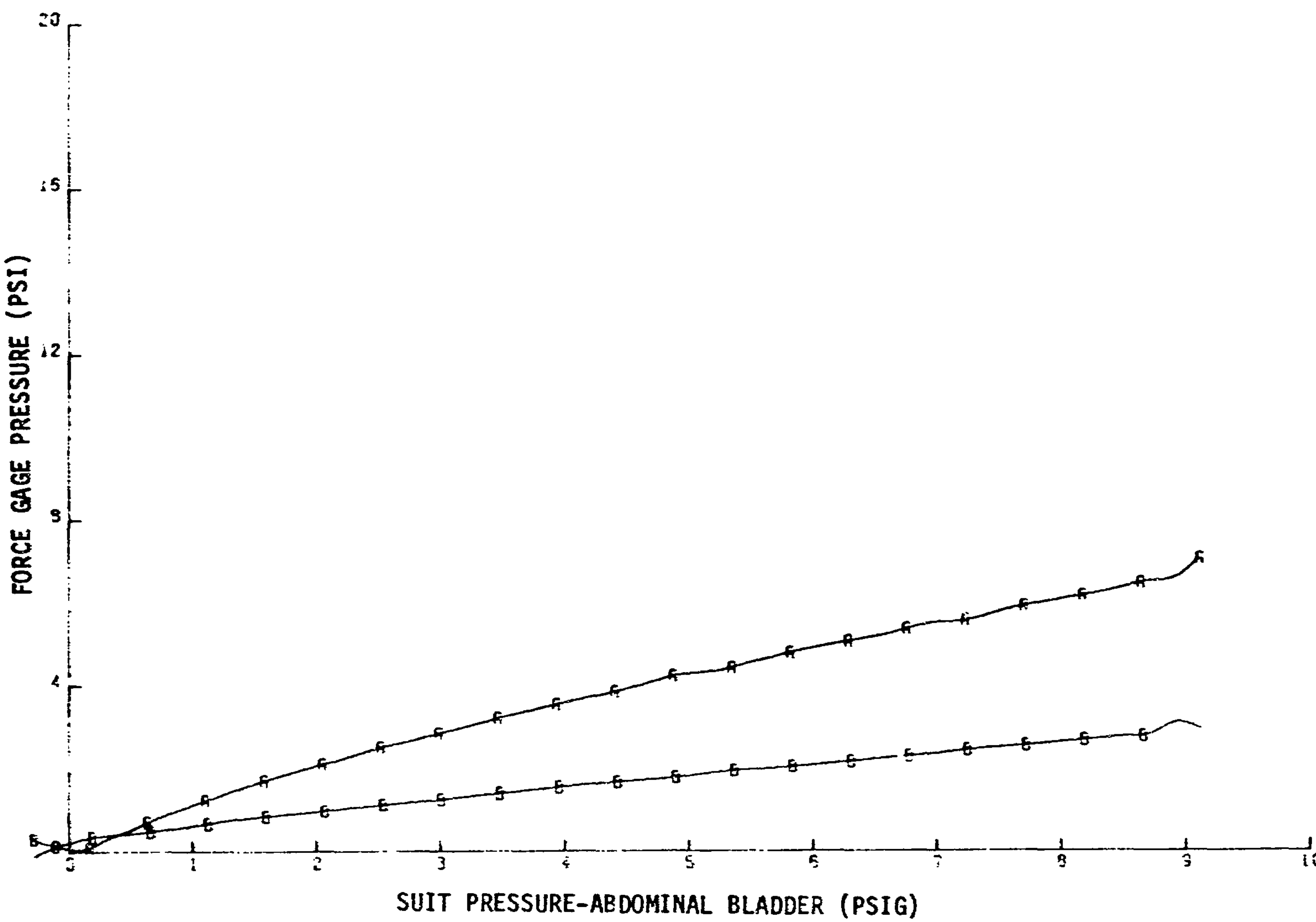

Figure 26. At 0.1 G_Z/sec--force gage pressure (abdomen and back) vs. abdominal bladder pressure. [Curves are: A and B. For "Key," refer to Table 48.]

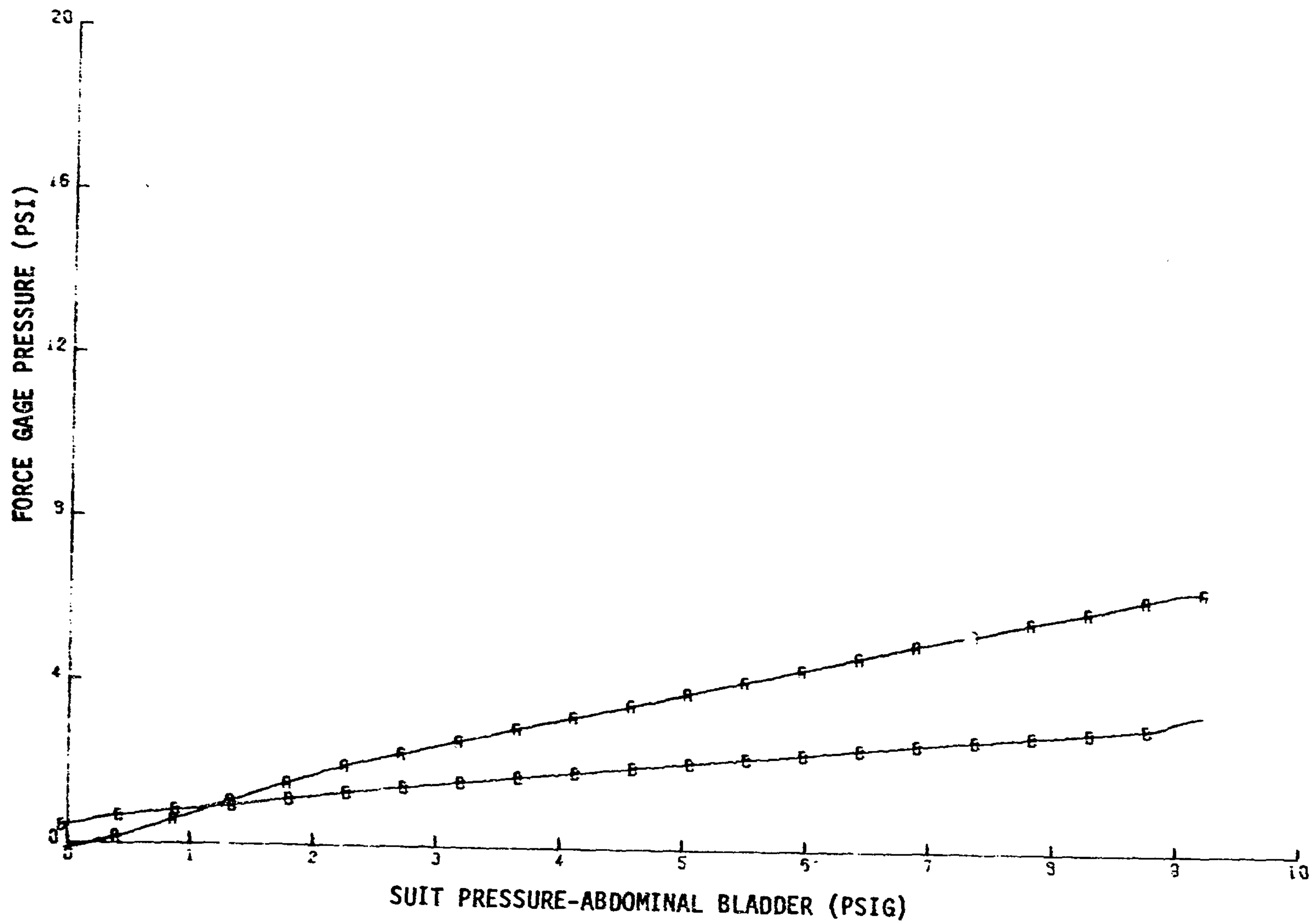

Figure 27. At 0.5 G_Z/sec--force gage pressure (abdomen and back) vs. abdominal bladder pressure. [Curves are: A and B. For "Key," refer to Table 48.]

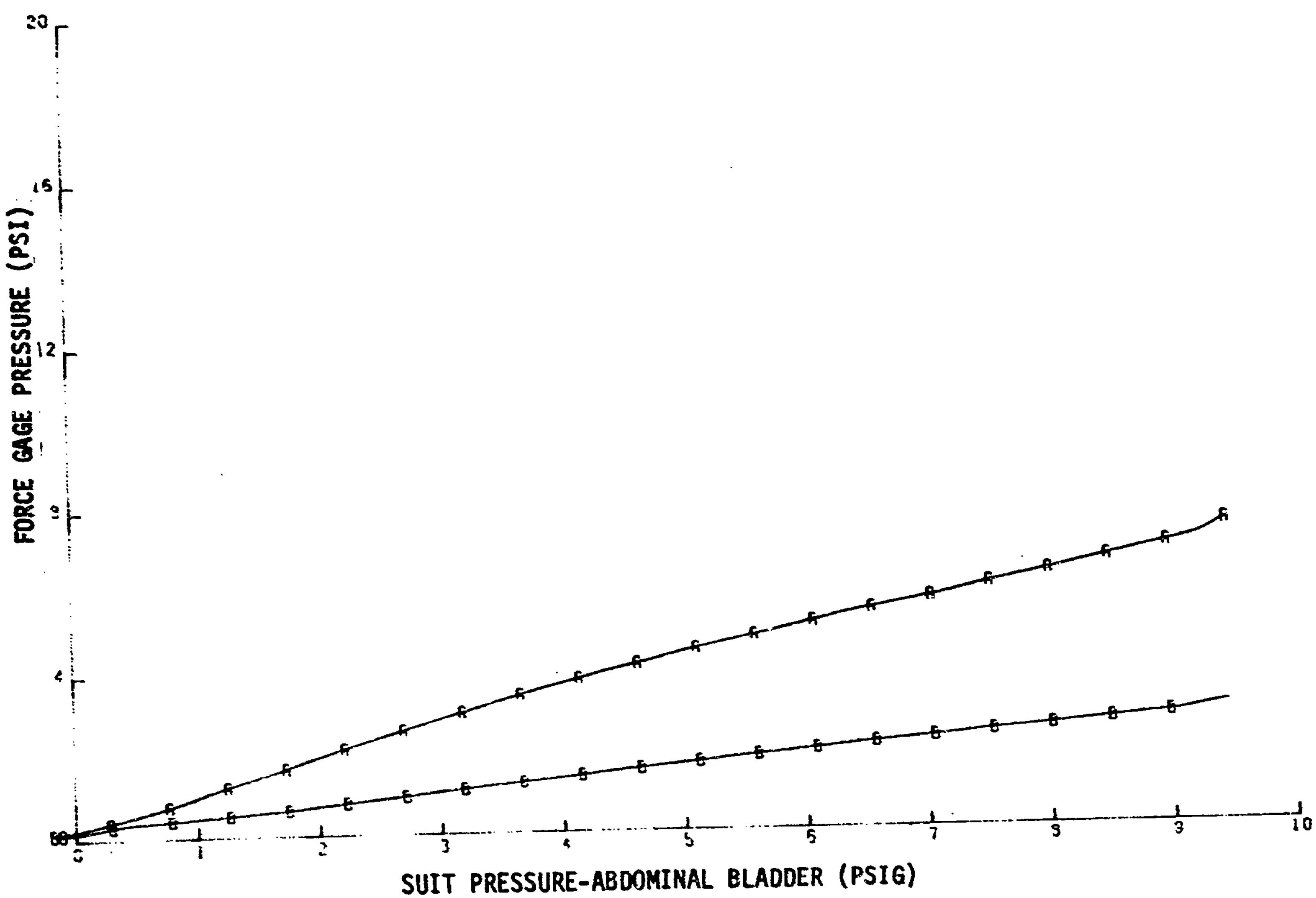

Figure 28. At 1.0 G_Z/sec--force gage pressure (abdomen and back) vs. abdominal bladder pressure. [Curves are: A and B. For "Key," refer to Table 48.]

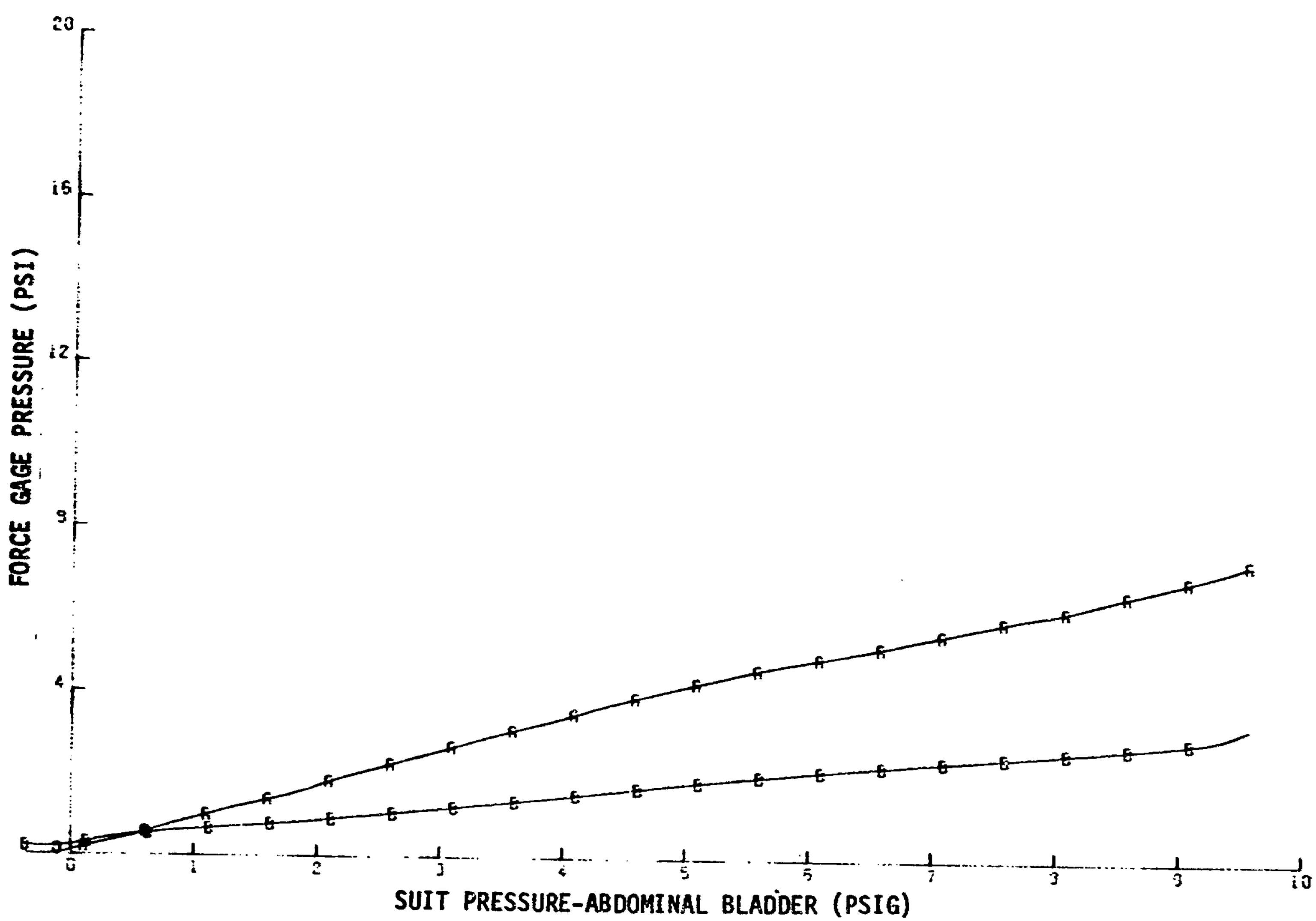

Figure 29. At 1.5 G_Z/sec--force gage pressure (abdomen and back) vs. abdominal bladder pressure. [Curves are: A and B. For "Key," refer to Table 48.]

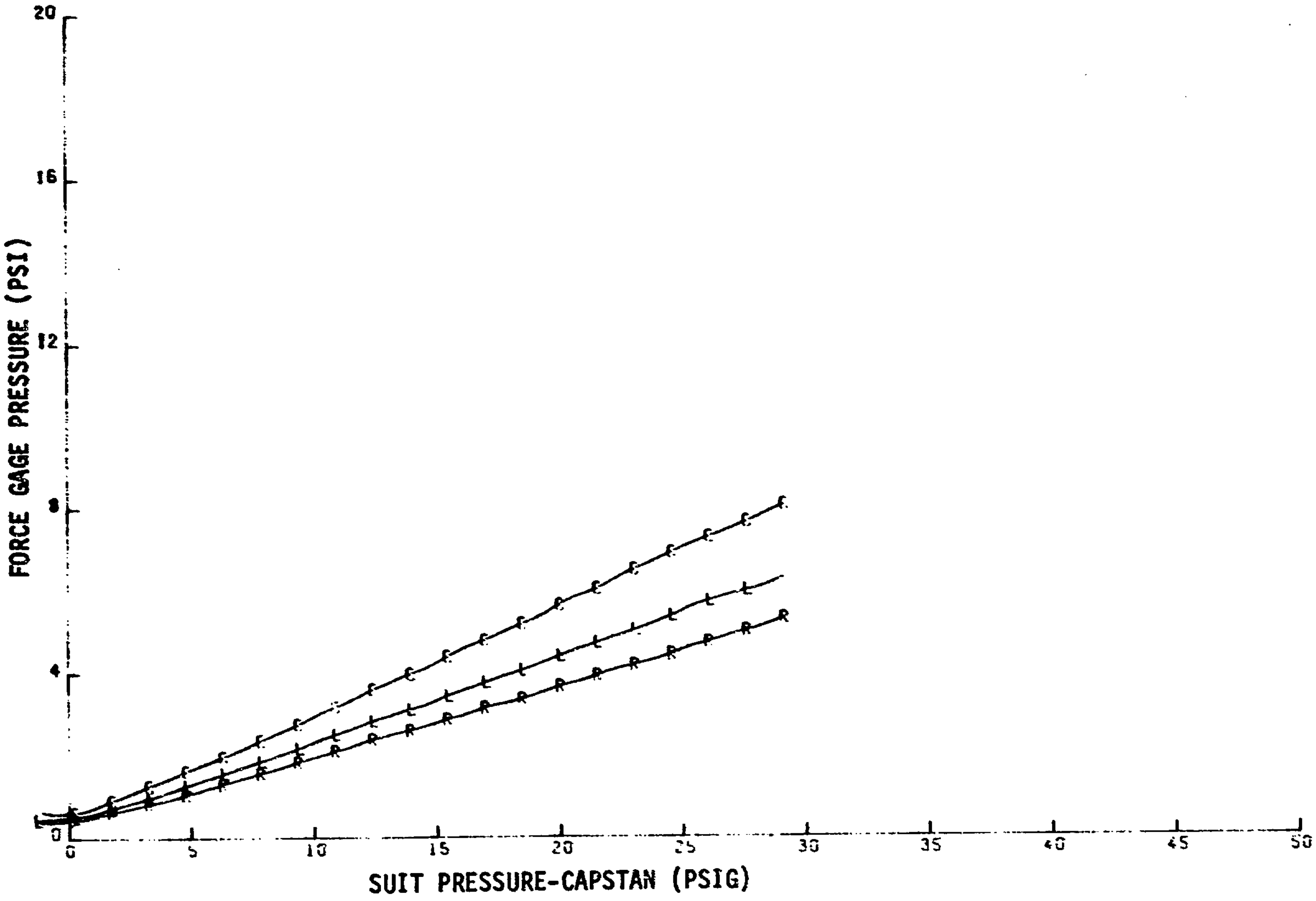

Figure 30. At 0.1 G_z/sec--force gage pressure (left calf and both thighs) vs. capstan pressure. [Curves are C, L, and R. For "Key," refer to Table 48.]

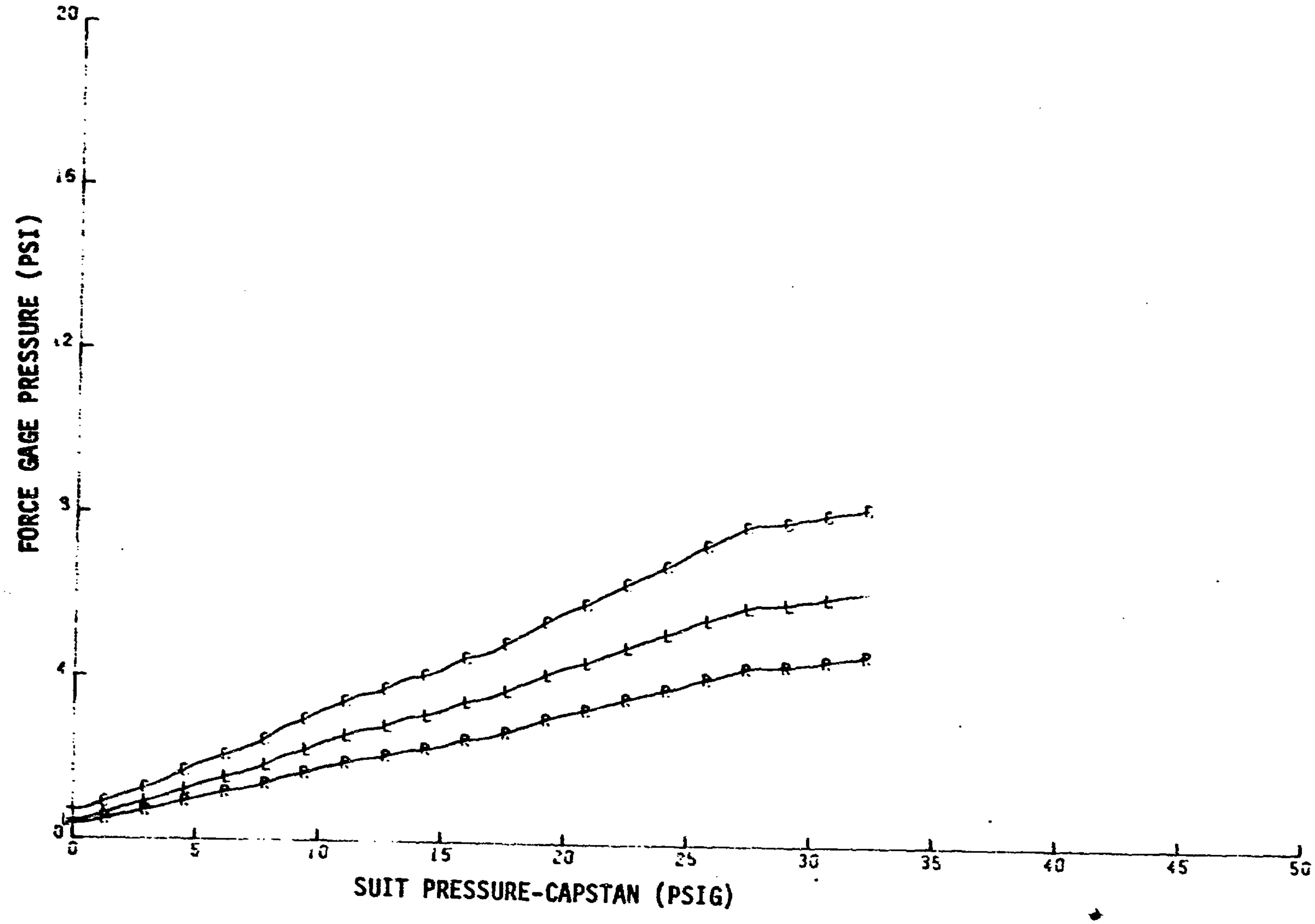

Figure 31. At 0.5 G_Z/sec--force gage pressure (left calf and both thighs) vs. capstan pressure. [Curves are C, L, and R. For "Key," refer to Table 48.]

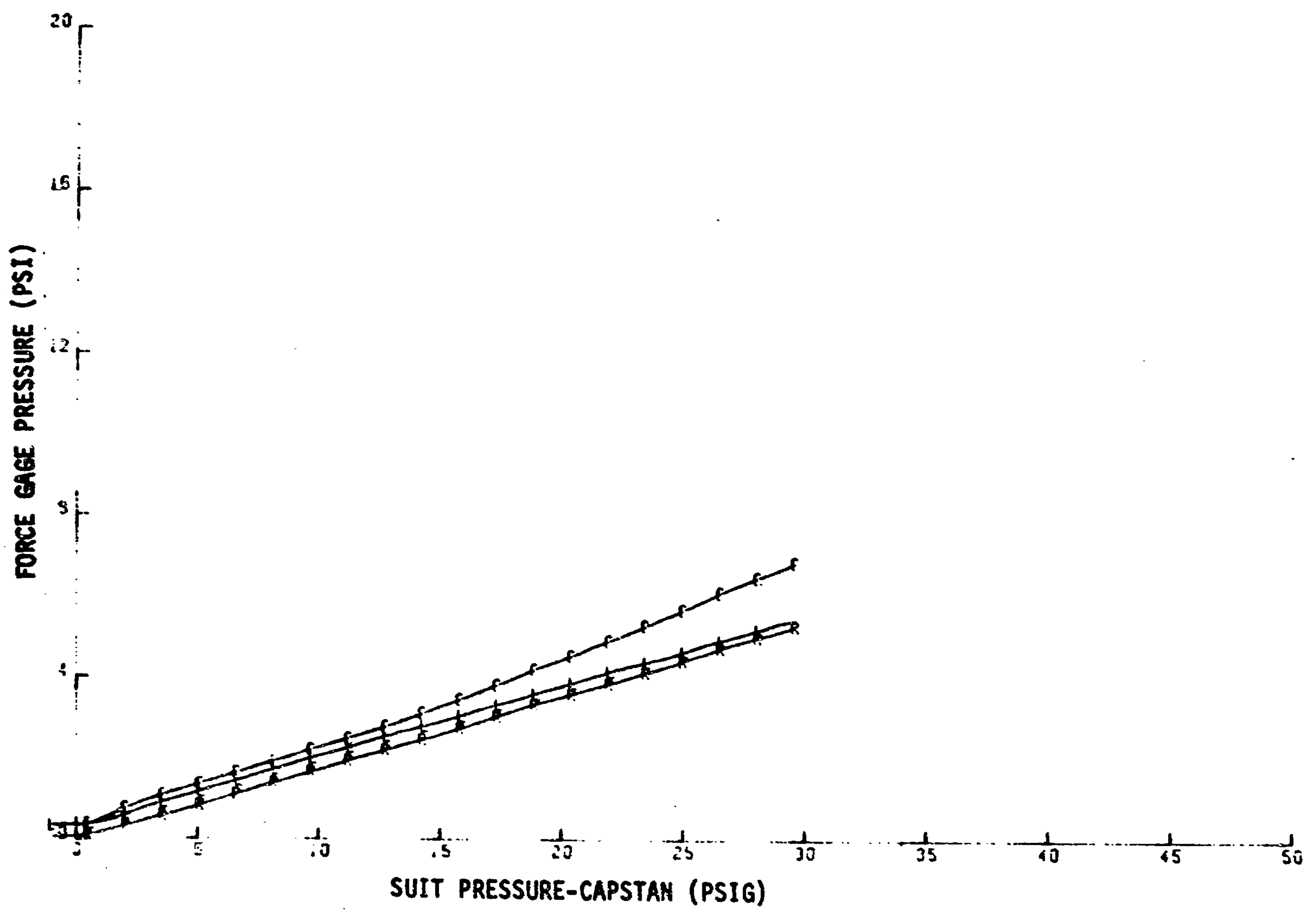

Figure 32. At 1.0 G_z/sec--force gage pressure (left calf and both thighs) vs. capstan pressure. [Curves are: C, L, and R. For "Key," refer to Table 48.]

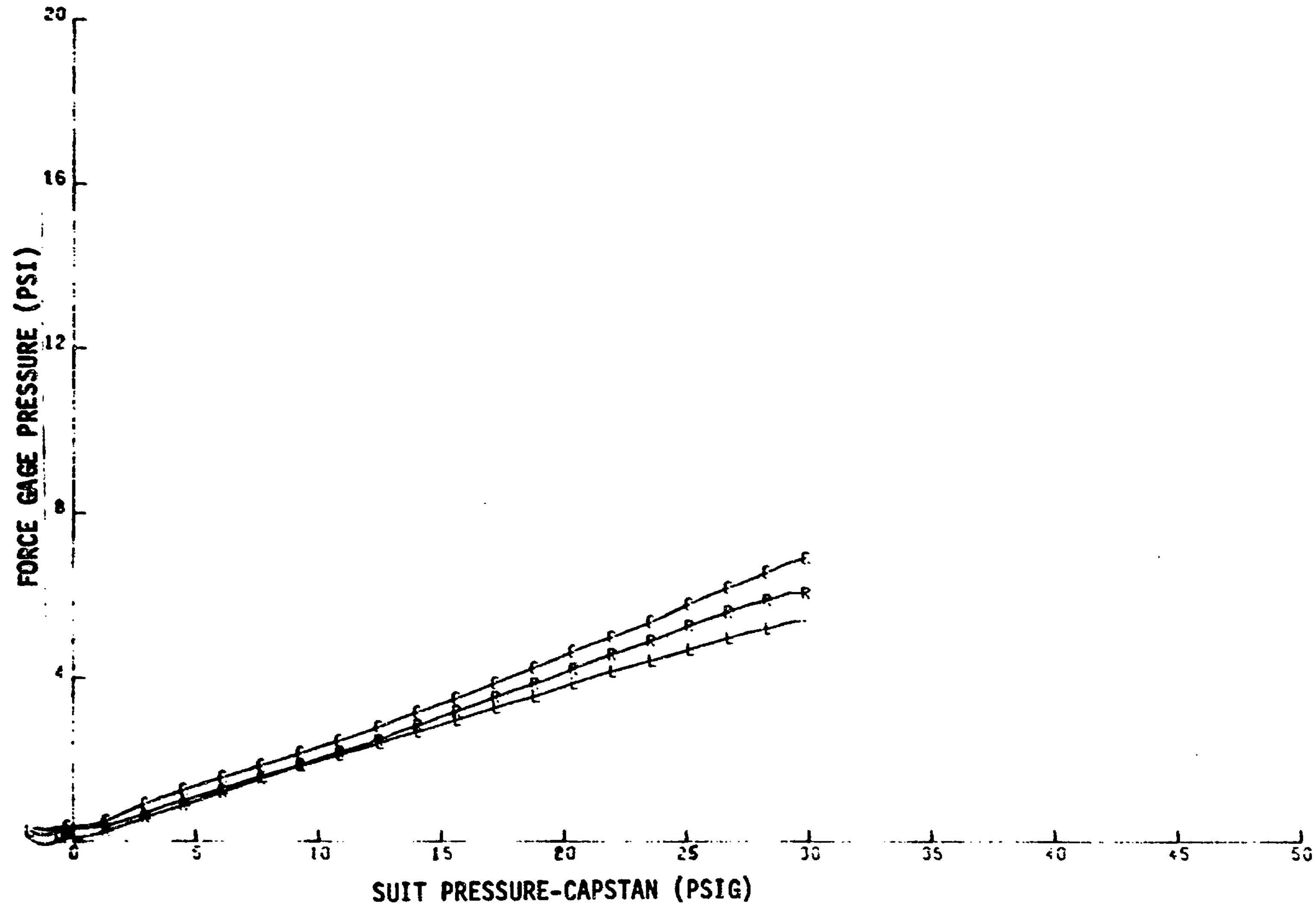

Figure 33. At 1.5 G_z/sec--force gage pressure (left calf and both thighs) vs. capstan pressure. [Curves are: C, L, and R. For "Key," refer to Table 48.]

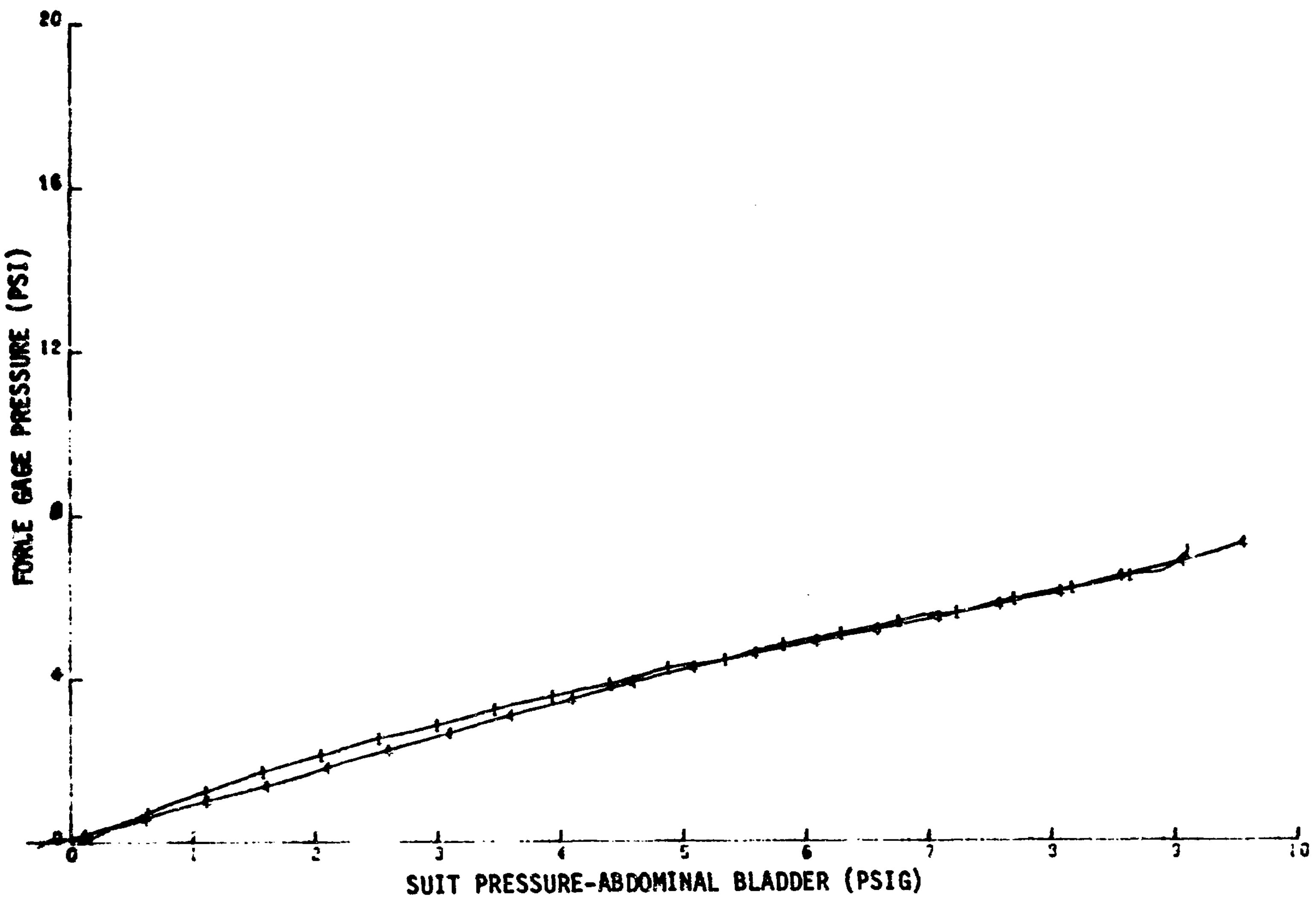

Figure 34. At 0.1 and 1.5 G_z/sec--force gage pressure (abdomen) vs. abdominal bladder pressure. [Curves are: 1 and 4. For "Key," refer to Table 48.]

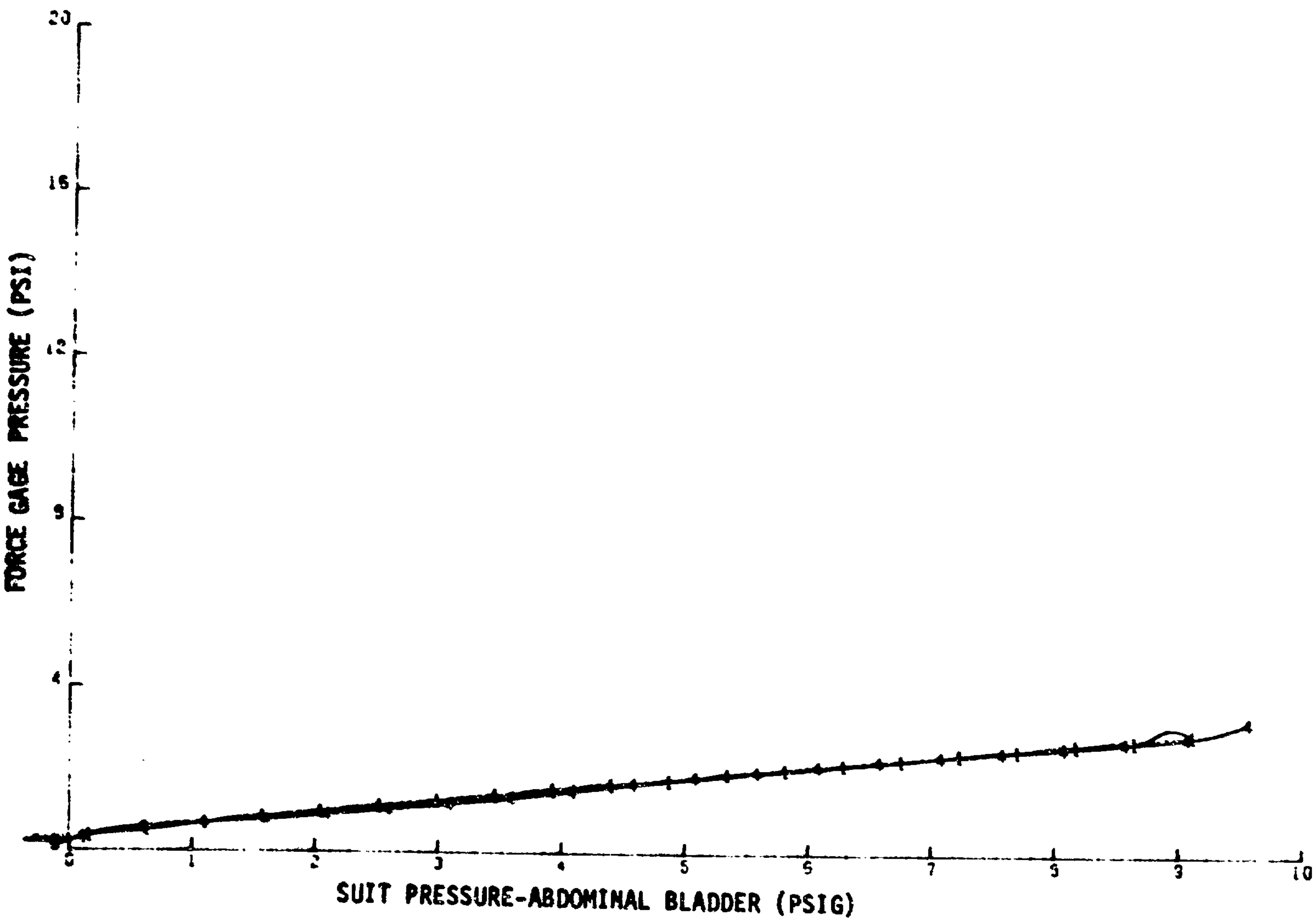

Figure 35. At 0.1 and 1.5 G_z/sec--force gage pressure (back) vs. abdominal bladder pressure. [Curves are: 1 and 4. For "Key," refer to Table 48.]

6.5.7 Thigh and Calf Interface Pressure vs. Capstan Pressure (Figs. 36 - 38)

In Figures 36 - 38, the curves show the pressure (psi) on the mannequin skin at the left and right thighs, and at the left calf, as a function of capstan pressure (psig). Curves for each limb are shown on separate charts which compare performance at 0.1 G/sec with that at 1.5 G/sec.

6.5.8 Compare Abdominal and Back Increasing and Decreasing Pressures vs. Bladder Pressures (Figs. 39 - 40)

In Figures 39 and 40, the curves show the mannequin skin pressure (psi) for increasing and decreasing G_z runs as a function of the suit pressures. Curves for the abdomen and back are shown on separate charts. All runs were made at 0.1 G/sec.

6.5.9 Compare Thigh and Calf Increasing and Decreasing Pressures vs. Capstan Pressure (Figs. 41 - 43)

In Figures 41 - 43, the curves show the mannequin skin pressure on the thighs and left calf (psi) vs. the capstan pressure (psig) for increasing and decreasing G_z runs. Curves for each limb are shown on separate charts. All runs were made at 0.1 G/sec.

6.5.10 Hysteresis Between Increasing and Decreasing Runs for the Abdominal Bladder (Figs. 44 - 45)

In Figures 44 and 45, the curves show the difference in abdominal and back skin pressures between increasing and decreasing G_z runs vs. abdominal bladder pressure. Curves for all four onset rates are shown on each chart. Curves for the abdomen and lower back are shown on separate charts.

6.5.11 Hysteresis Between Increasing and Decreasing Runs for the Capstan (Figs. 46 - 48)

In Figures 46 - 48, the curves show the difference in limb skin pressures between increasing and decreasing G_z runs vs. capstan pressure. Curves for all four onset rates are shown on each chart. Curves for each limb are plotted on separate charts.

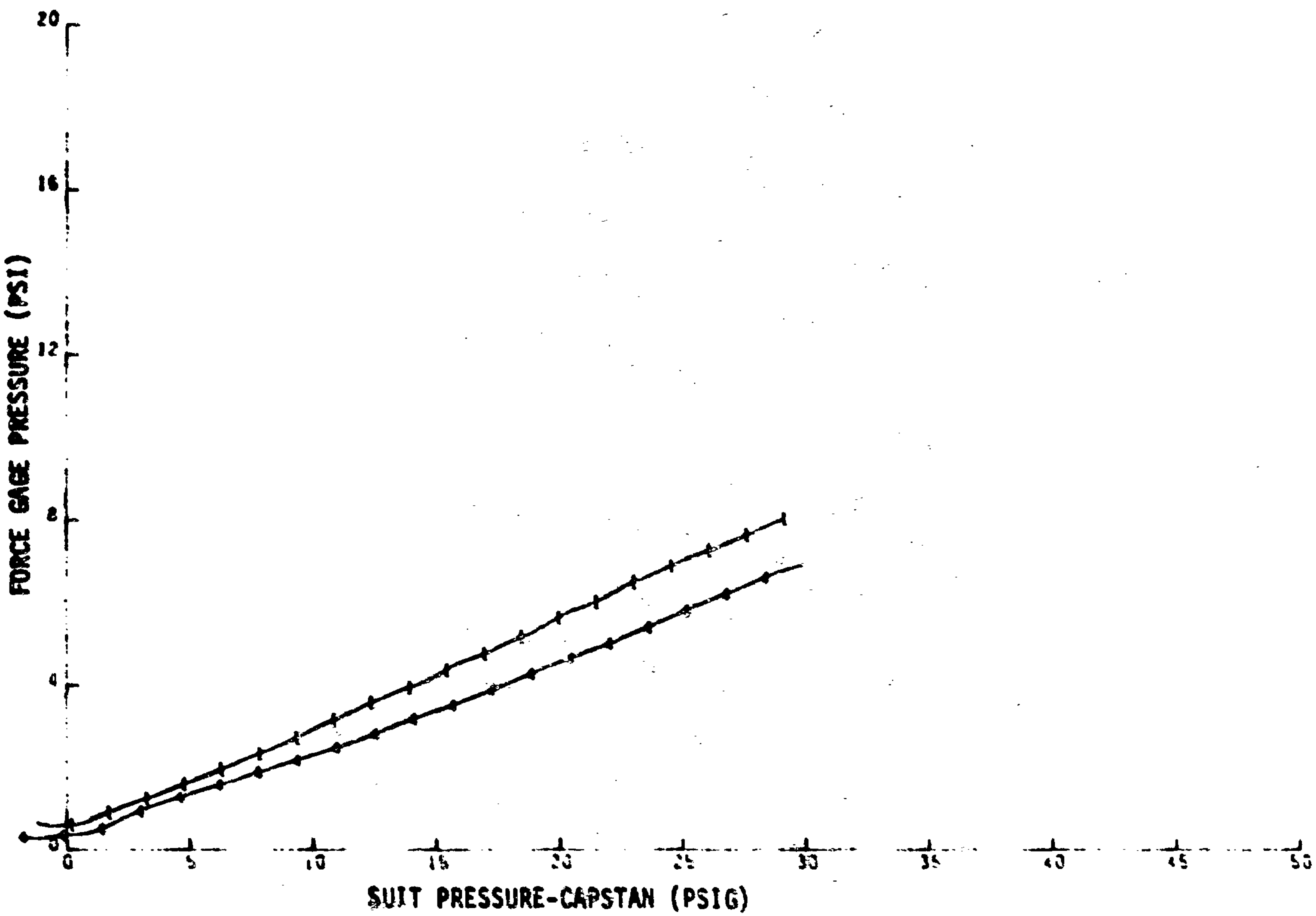

Figure 36. At 0.1 and 1.5 G_z/sec--force gage pressure (left calf) vs. capstan pressure. [Curves are: 1 and 4. For "Key," refer to Table 48.]

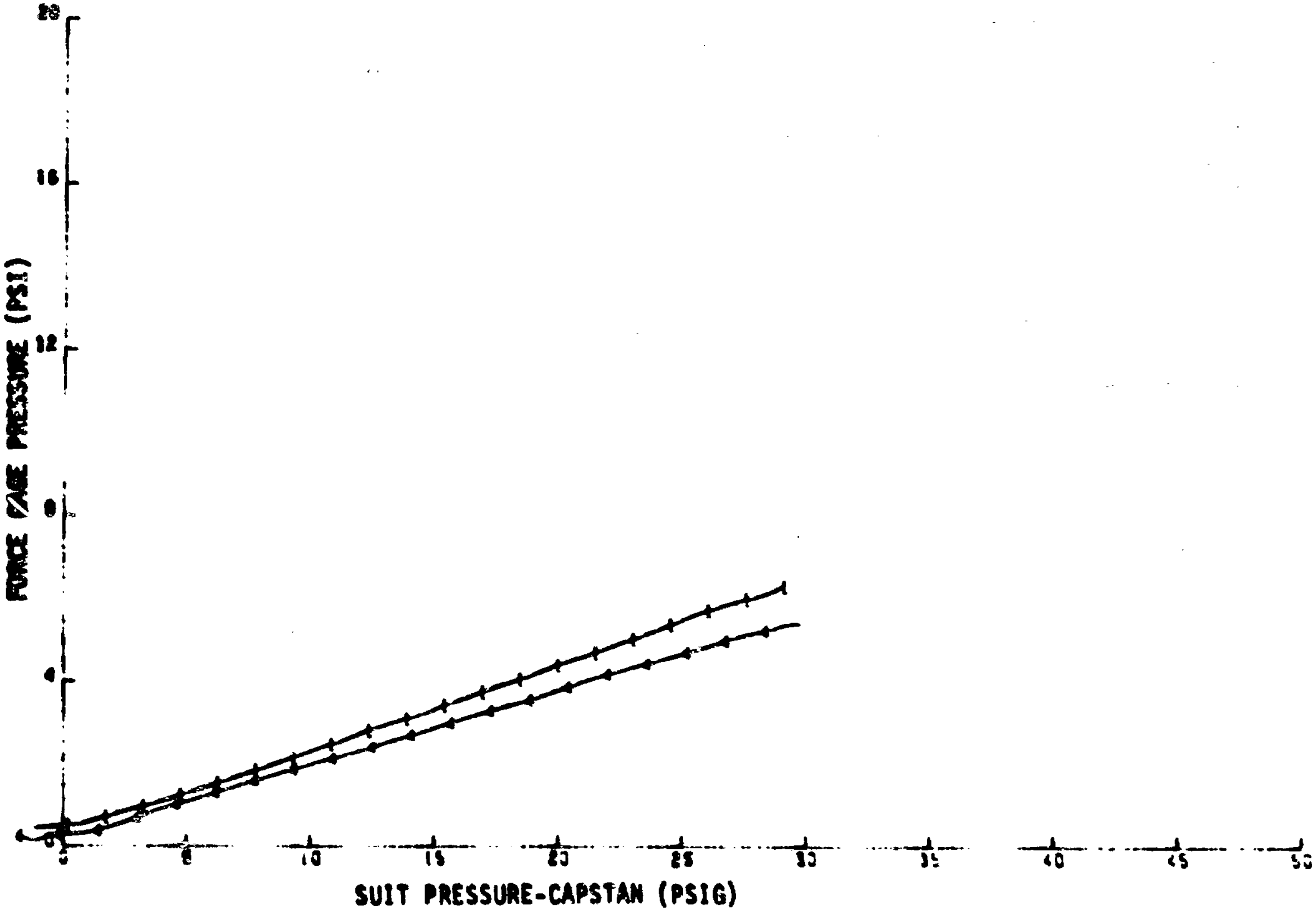

Figure 37. At 0.1 and 1.5 G_z/sec--force gage pressure (left thigh) vs. capstan pressure. [Curves are: 1 and 4. For "Key," refer to Table 48.]

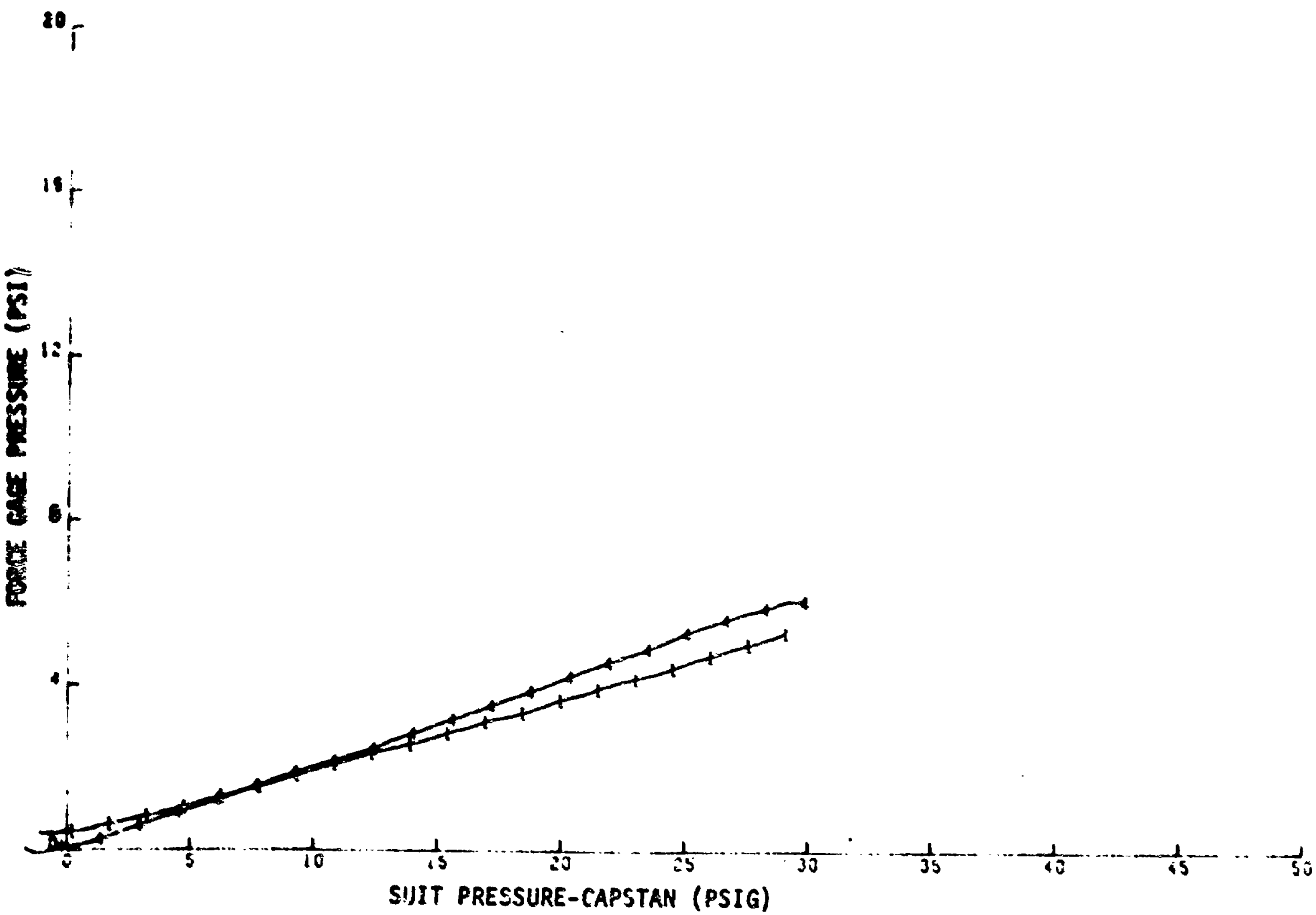

Figure 38. At 0.1 and 1.5 G_z/sec--force gage pressure (right thigh) vs. capstan pressure. [Curves are: 1 and 4. For "Key," refer to Table 48.]

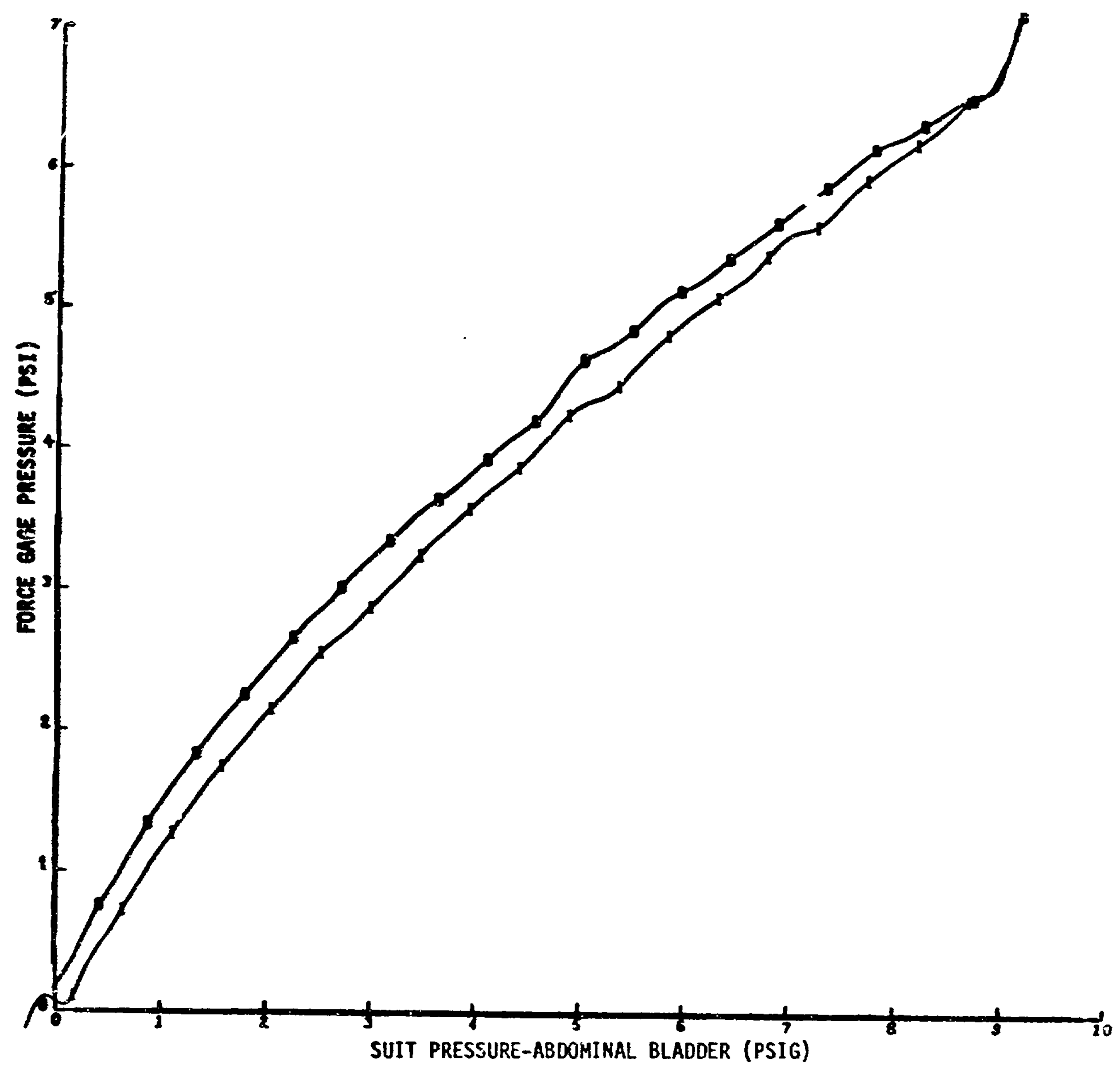

Figure 39. At 0.1 G_z/sec--force gage pressure (abdomen) vs. abdominal bladder pressure. [Curves are: I and D. For "Key," refer to Table 48.]

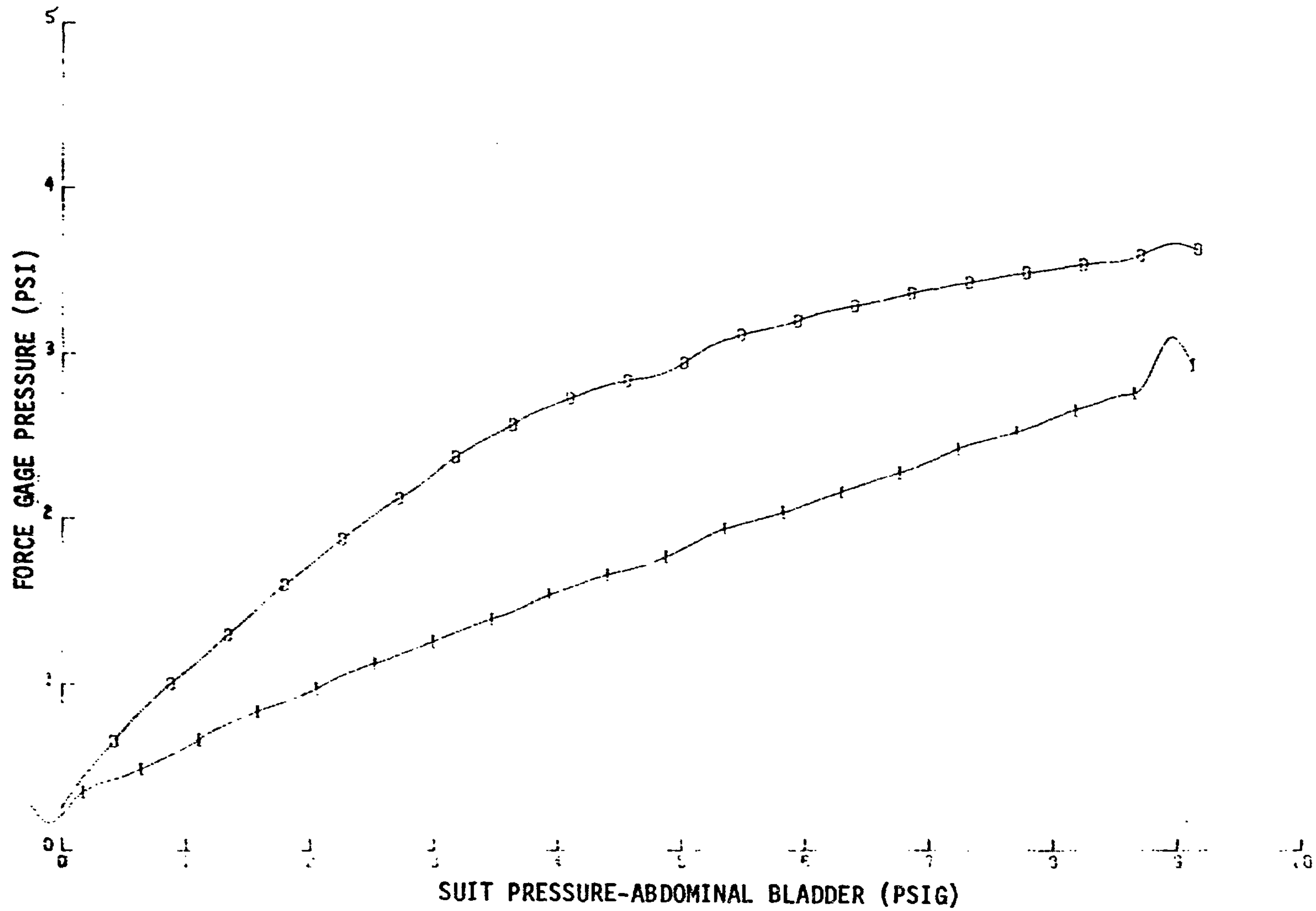

Figure 40. At 0.1 G_Z/sec--force gage pressure (back) vs. abdominal bladder pressure for increasing and decreasing G_Z. [Curves are: I and D. For "Key," refer to Table 48.]

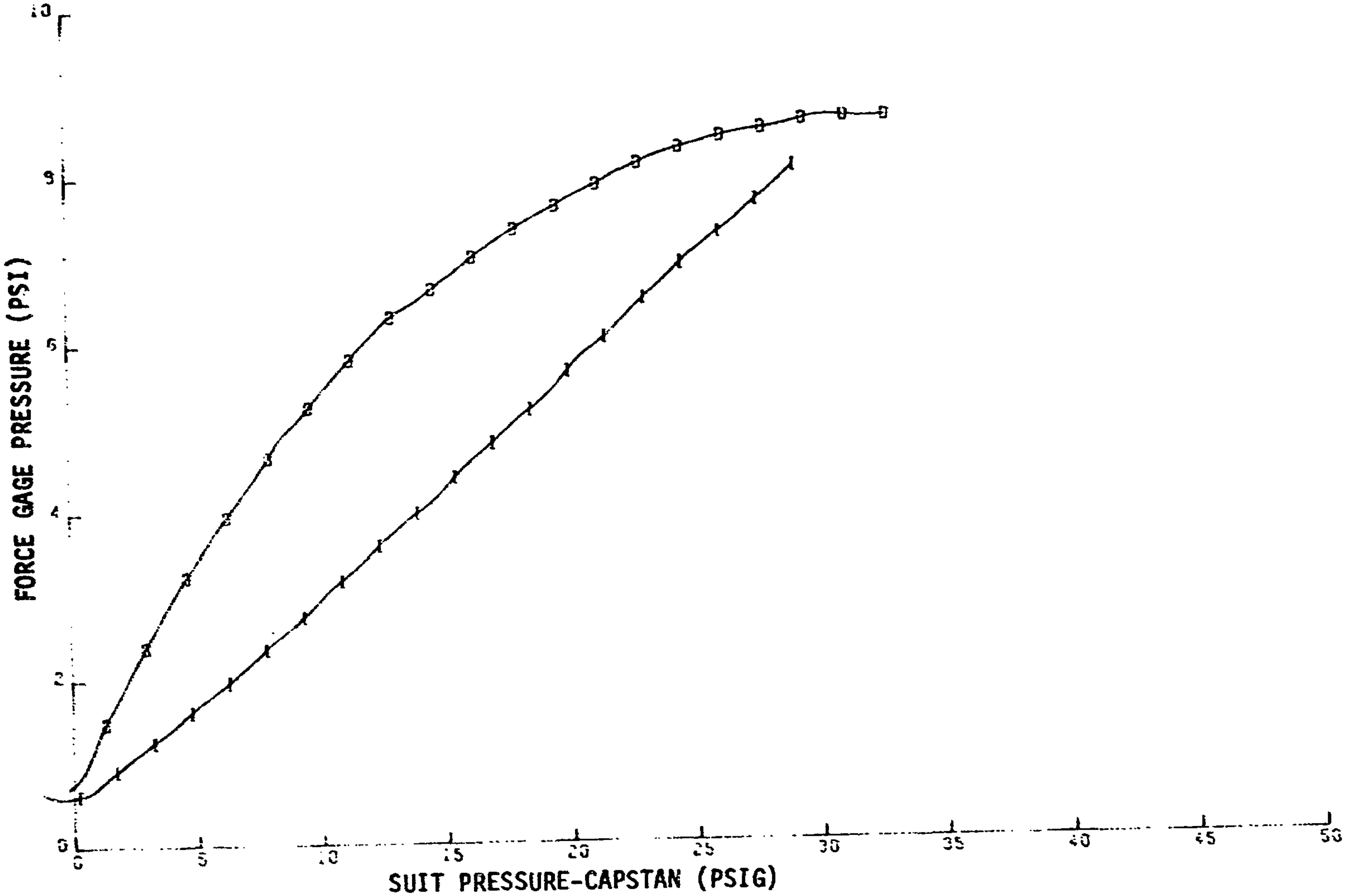

Figure 41. At 0.1 G_z/sec--force gage pressure (left calf) vs. capstan pressure for increasing and decreasing G_z. [Curves are: I and D. For "Key," refer to Table 48.]

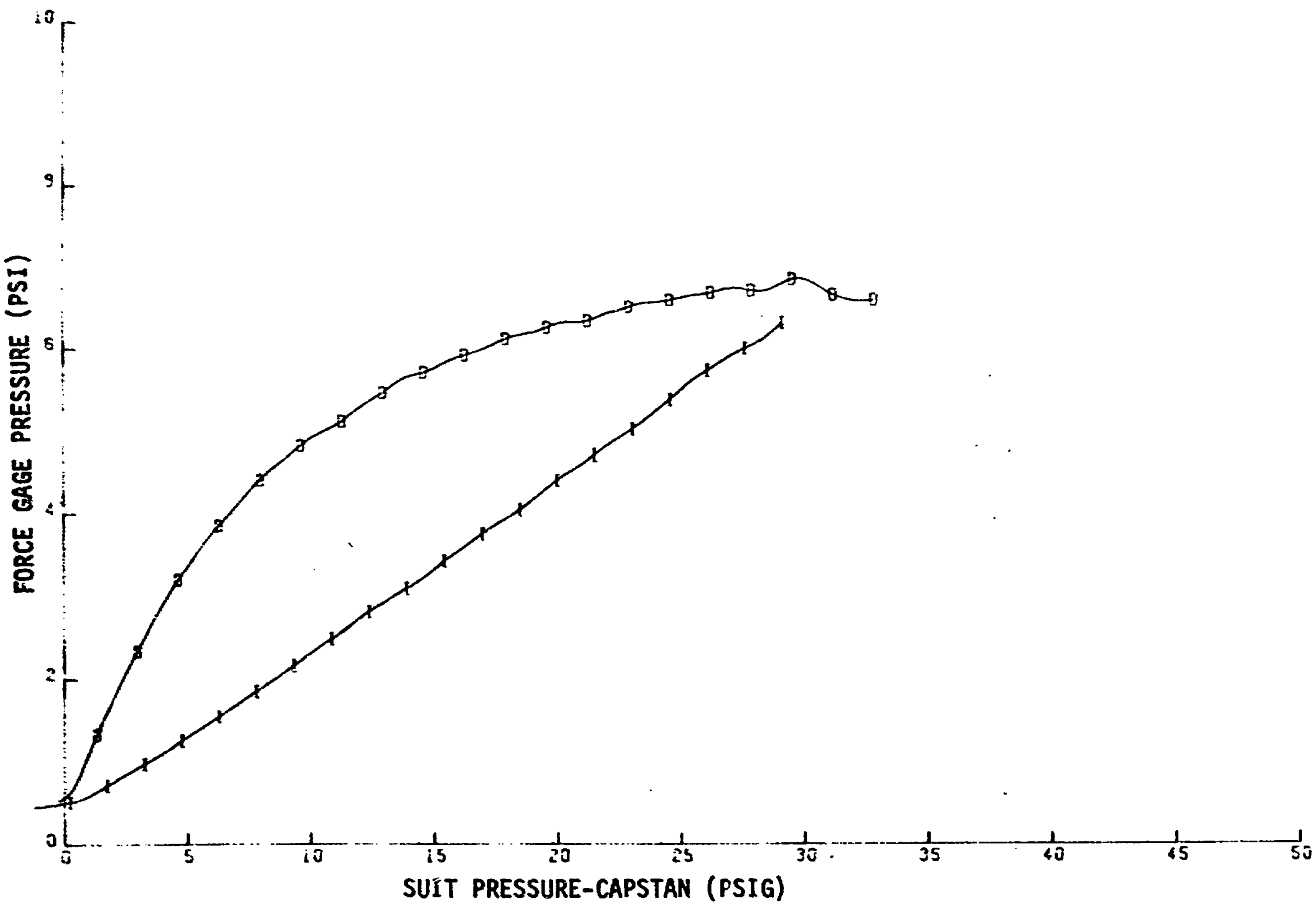

Figure 42. At 0.1 G_z/sec--force gage pressure (left thigh) vs. capstan pressure for increasing and decreasing G_z. [Curves are: I and D. For "Key," refer to Table 48.]

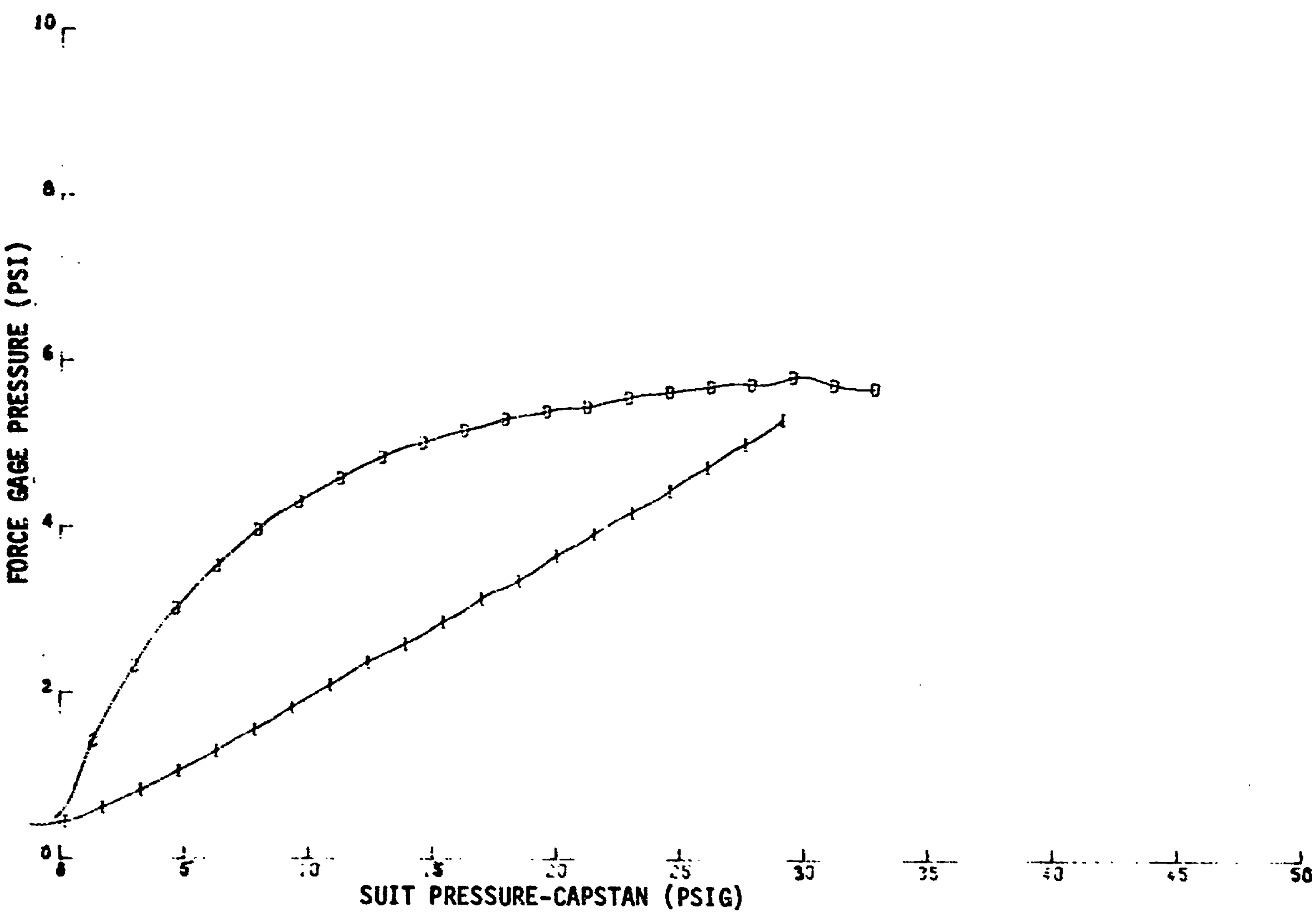

Figure 43. At 0.1 G_Z/sec--force gage pressure (right thigh) vs. capstan pressure for increasing and decreasing G_Z. [Curves are: I and D. For "Key," refer to Table 48.]

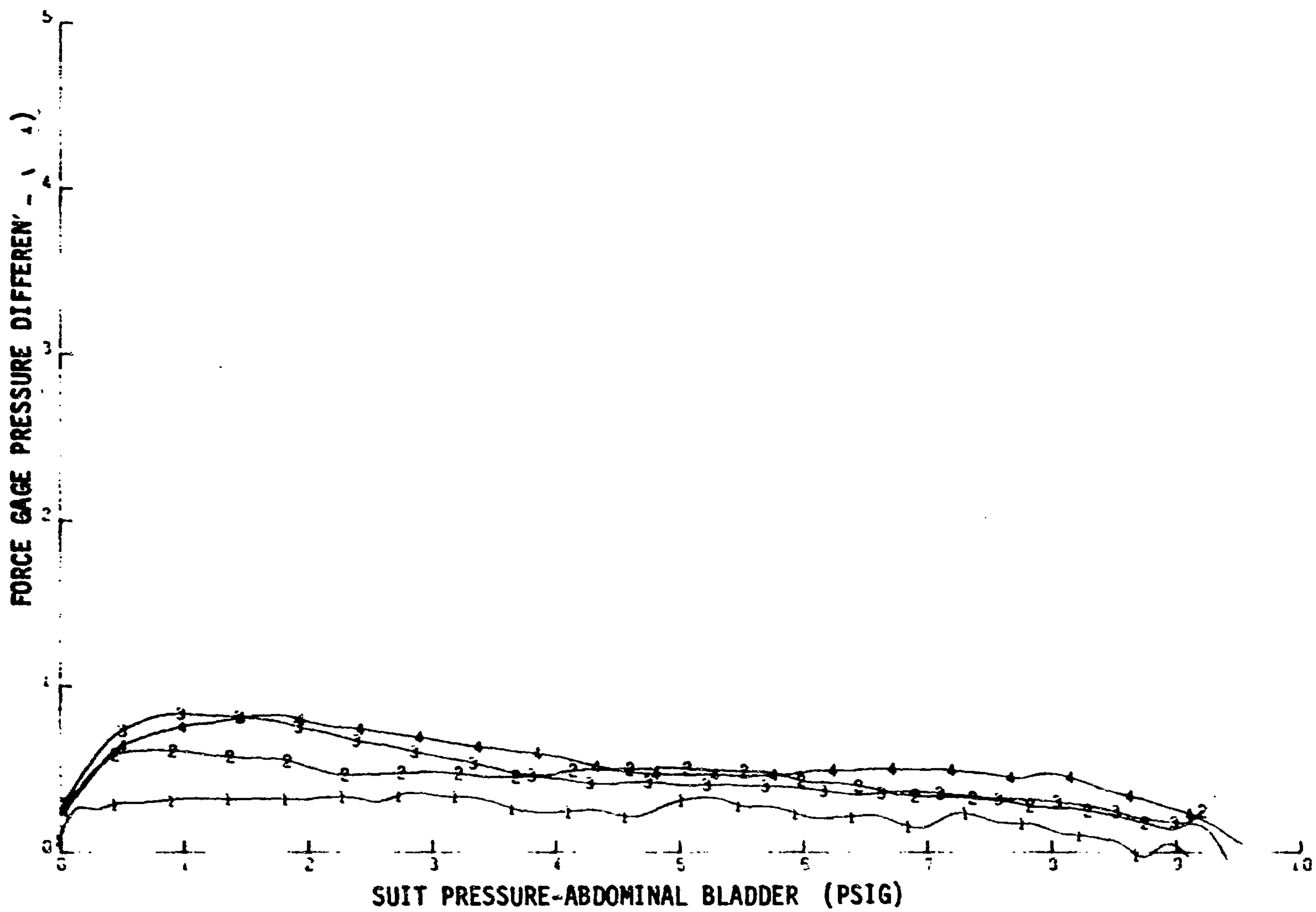

Figure 44. For four onset rates--force gage pressure difference (abdomen) between increasing and decreasing G_z runs vs. abdominal bladder pressure. [Curves are: 1, 2, 3, 4. For "Key," refer to Table 48.]

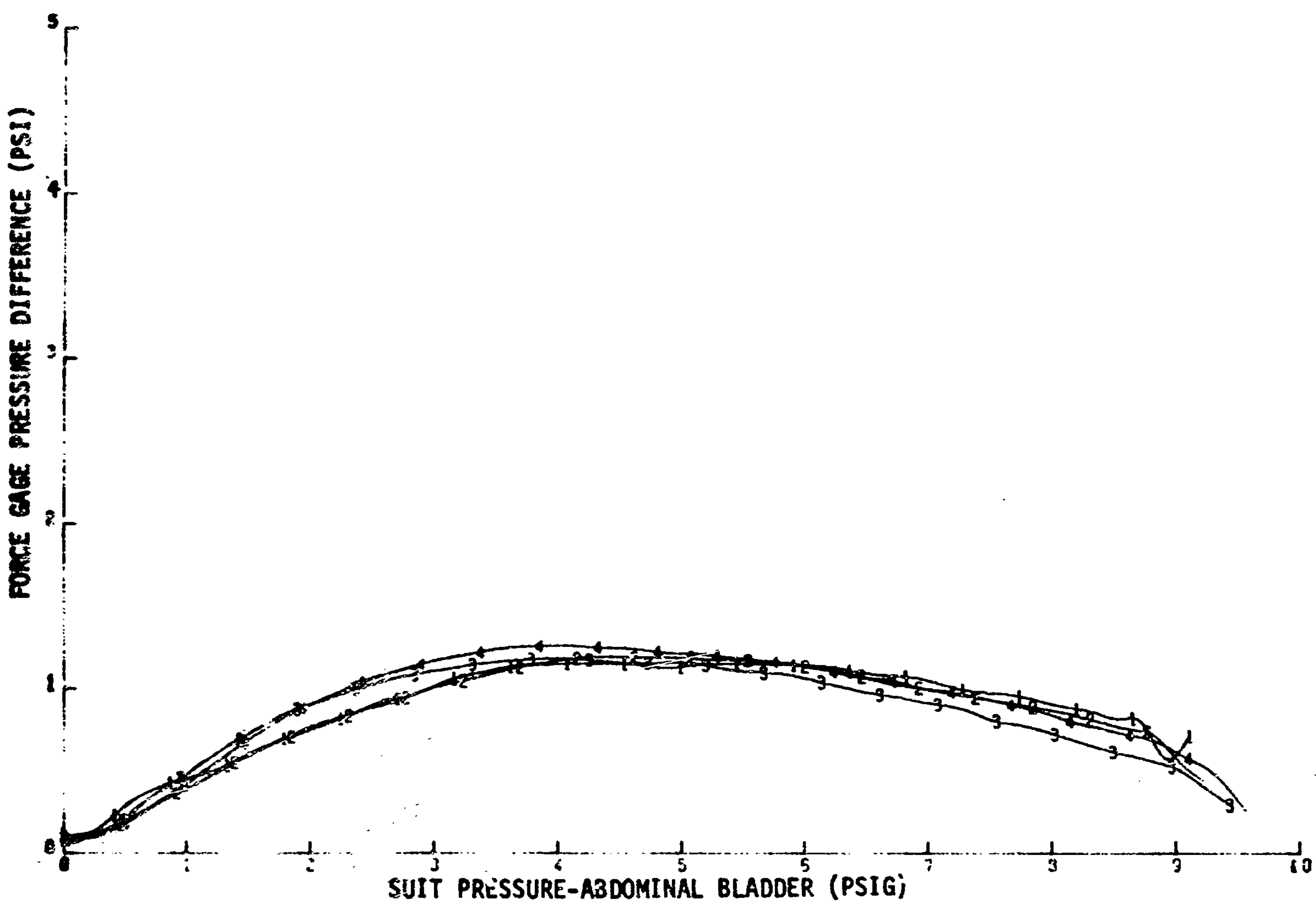

Figure 45. For four onset rates--force gage pressure difference (back) between increasing and decreasing G_z runs vs. abdominal bladder pressure. [Curves are: 1, 2, 3, and 4. For "Key," refer to Table 48.]

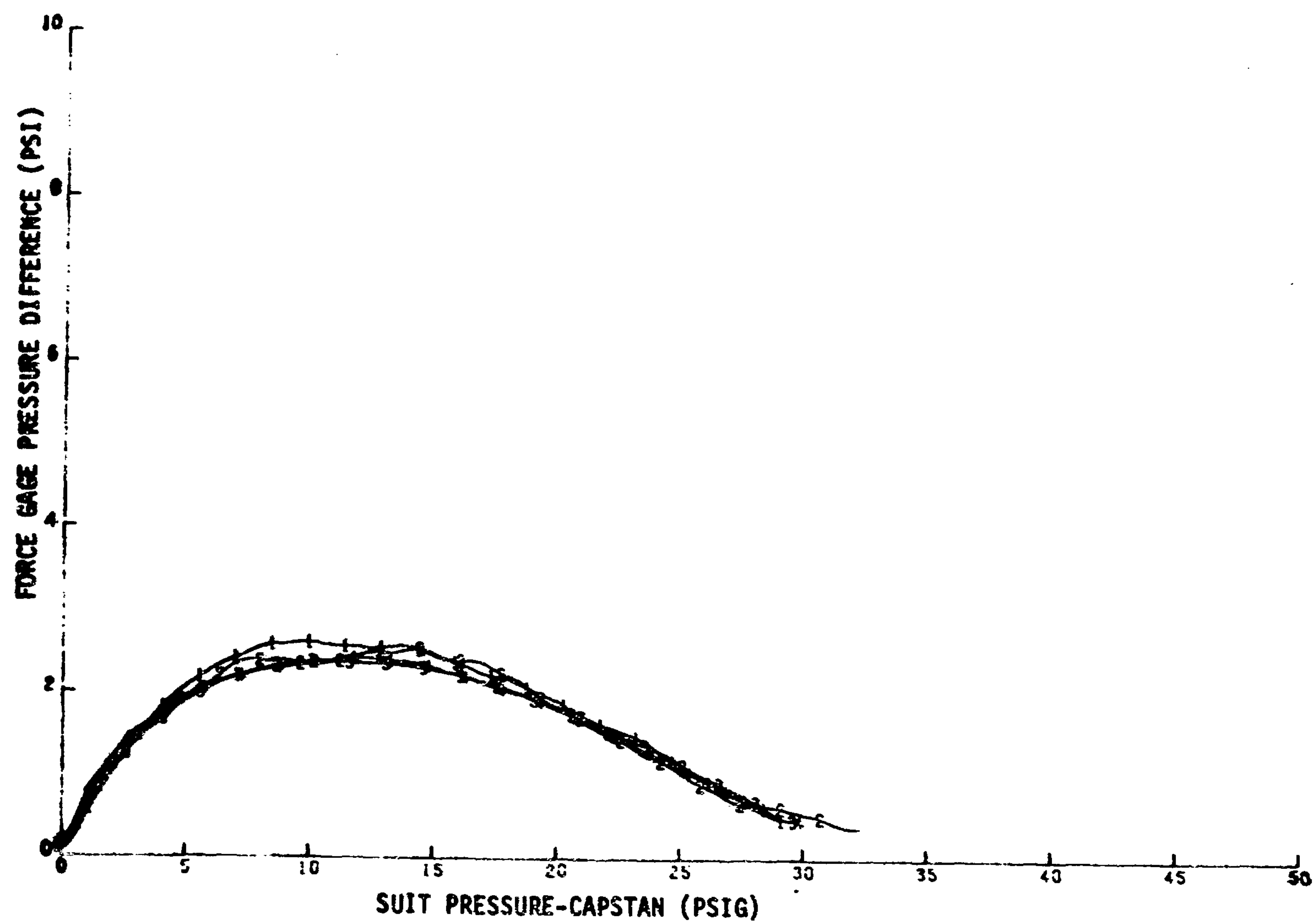

Figure 46. For four onset rates--force gage pressure difference (left thigh) between increasing and decreasing G_z runs vs. capstan pressure. [Curves are: 1, 2, 3, and 4. For "Key," refer to Table 48.]

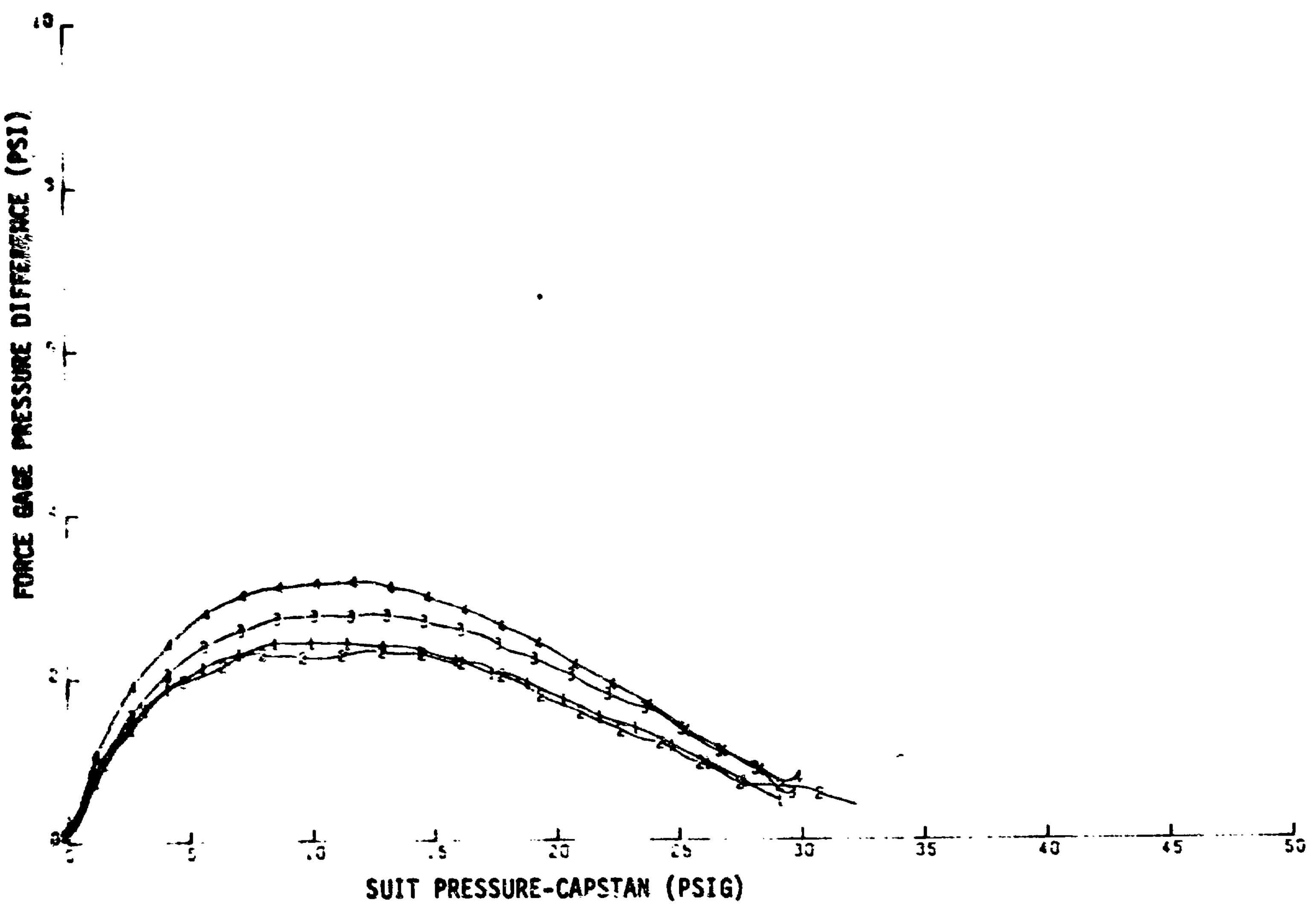

Figure 47. For four onset rates--force gage pressure difference (right thigh) between increasing and decreasing G_z runs vs. capstan pressure. [Curves are: 1, 2, 3, and 4. For "Key," refer to Table 48.]

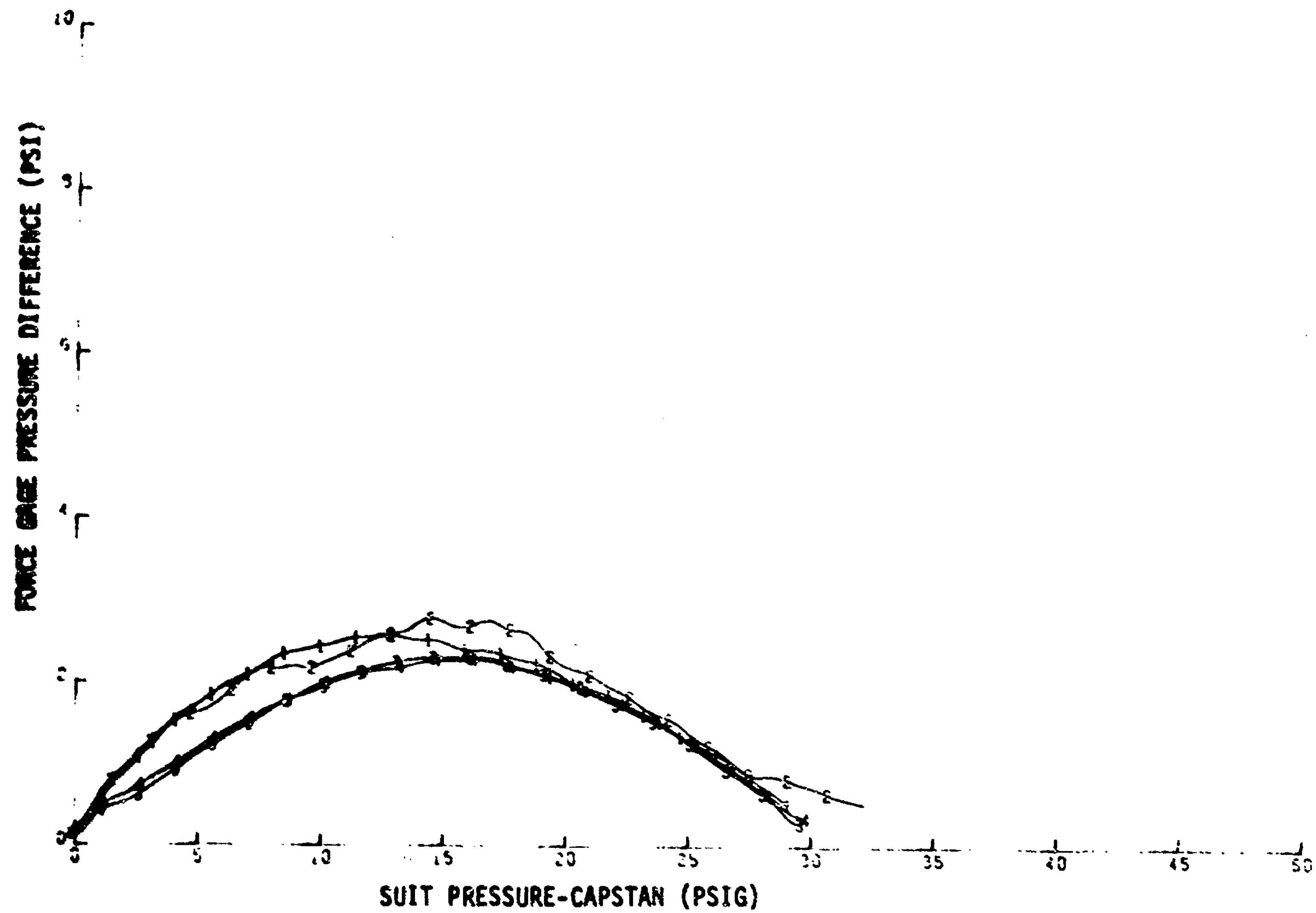

Figure 48. For four onset rates--force gage pressure difference (left calf) between increasing and decreasing G_z runs vs. capstan pressure. [Curves are: 1, 2, 3, and 4. For "Key," refer to Table 48.]

6.5.12 SACM Runs for Abdominal Bladder (Fig. 49)

In Figure 49, the curve shows abdominal and back skin pressures, abdominal bladder pressures, and acceleration vs. time for SACM runs. Abdominal and lower back curves are plotted separately on the same graph.

6.5.13 SACM Runs for Capstan (Fig. 50)

In Figure 50, the curve shows limb skin pressures, capstan pressures, and acceleration vs. time for SACM runs. Curves for the left and right thigh, and the left calf, are plotted separately on the same graph.

6.6 Review of Test Results

The primary purpose of this series of tests (in section 6) has been to establish the quantitative relationship between pressure in the capstan and the resulting pressure against the skin of the mannequin. In reviewing the results of these tests, one should remember that they were conducted using a solid mannequin as a test subject--and that actual skin pressure on a human subject might be somewhat different.

Because the results of Phase IV (in section 6.4.4) have been used to scale the data obtained from the force buttons mounted on the mannequin during the tests, these results are discussed first. As already explained (in section 6.4.4), the water-filled bag was used in conjunction with the force button, at each location, to find a scale factor for converting the force button output voltage to actual suit-mannequin interface pressure. A series of three to five runs were made with the water bag at each location, from 0 to 50 psig for the capstans, and from 0 to 10 psig for the abdominal bladder. After the results of these runs were plotted, the slopes of the resulting lines were calculated as follows:

Right calf	*
Left calf	0.946 psi/lbf
Left thigh	1.308 psi/lbf
Right thigh	1.505 psi/lbf
Abdomen	1.621 psi/lbf
Back	1.083 psi/lbf

* Because both the force on the abdomen and the force on the back were to be tested, the force button had to be removed from the right calf to use on the back. Consequently, no data on the right calf were taken.

These slopes were used in the computer preparation of the data curves resulting from these tests. Therefore, whenever a graph is scaled in "Force Gage Pressure," it is in actual pressure (in psi) of the suit interface with the skin.

A review of Figures 24 and 25 shows that the suit response to varying onset rates of increasing G_Z is very good. Although the data in Figures 24 and 25 include the effects of the anti-G valves selected for this test, these curves show that the flow capability of the suit--both in the bladder and capstans--is sufficient to follow very closely the onset rates of up to 1.5 G/sec. The abdominal bladder (Fig. 24) does start to lag slightly in the 3 - 5 G range, but stays within very acceptable limits. Figures 34 and 35 also indicate the very "tight" relationship of bladder pressure and abdominal and back interface pressure when the slowest (0.1 G/sec) and the fastest (1.5 G/sec) onset rates are compared.

Examination of Figures 26 - 29 shows the linearity of the relationship between bladder pressure and the suit-skin pressure, both on the abdomen and lower back. It should be noted that the abdominal pressure is slightly more than twice the back pressure at all onset rates. The maximum pressure on the abdomen was about 8 psi, with the bladder suit pressure at 9.5 psig.

Figures 30 - 33 show the relationship of capstan pressure to limb interface pressures. The left calf leads both thighs at all onset rates. This finding was expected, since the suit was fitted with a higher force ratio (4:1) in the calves than in the thighs (6:1). Moreover, the left thigh leads the right thigh in all cases. It was noted during testing (especially by the human subject who wore this suit) that a significant time lag occurred between the left capstan, where the inlet hose is connected, and the right capstan. Although the lag of the right side would therefore have been expected to be more pronounced at the higher onset rates, such (inexplicably) is not the case.

Examination of suit hysteresis (Figs. 39 - 43) shows that the suit tends to maintain interface pressure for a significant time after bladder or capstan pressure has been lowered. This effect is much more evident on the capstans than on the bladder. It is thought that this difference is caused by the suit being held in place, after it has been pulled tight, by the frictional forces existing between the suit and the mannequin.

An overall view of abdominal bladder performance is presented in Figure 49. These data, resulting from a SACM run, show the extremely close relationship of abdominal bladder pressure and suit interface pressure at the abdomen. Note that, during this run, these two pressures could not be separated by the computer and appear as a single curve.

The performance of the capstans in a SACM run is shown in Figure 50. The interface pressures stay quite close together during the run, indicating a fairly uniform performance. However, they fall far below the pressure curve on the extremely fast onset rates of the SACM. (It is not known

how much of this effect is due to the anti-G valve performance, because the Capstan Anti-G Valve was not tested during the TEHG program.)

Evaluation of the physiologic significance of these data is beyond the scope of this effort. The exceptionally fast response time of the capstan system tested is emphasized, and its capacity for adjustment of force ratios along the leg may be significant. However, the conduct of these tests re-emphasized to the investigators the operational difficulties associated with the Capstan Anti-G Suit. Any subsequent evaluation of relative merit between Capstan Anti-G Suits and conventional 3- or 5-bladder anti-G suits must consider the trade-offs between performance and application difficulty as they relate to and affect the mission.

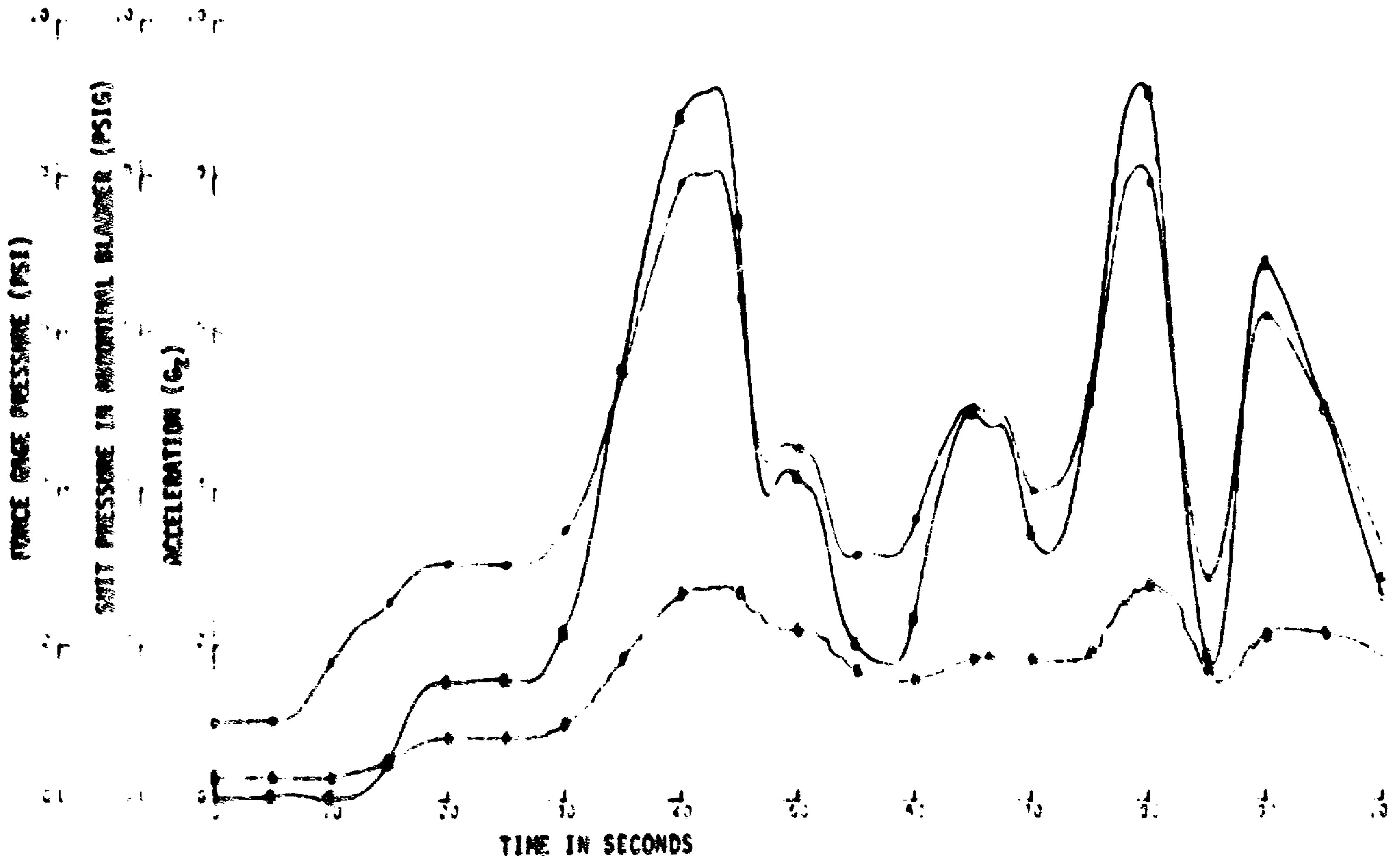

Figure 49. The G_z, abdominal bladder pressure, and force gage pressure (back) vs. time, for a simulated aerial combat maneuver. [Curves are: S and B. For "Key," refer to Table 48.]

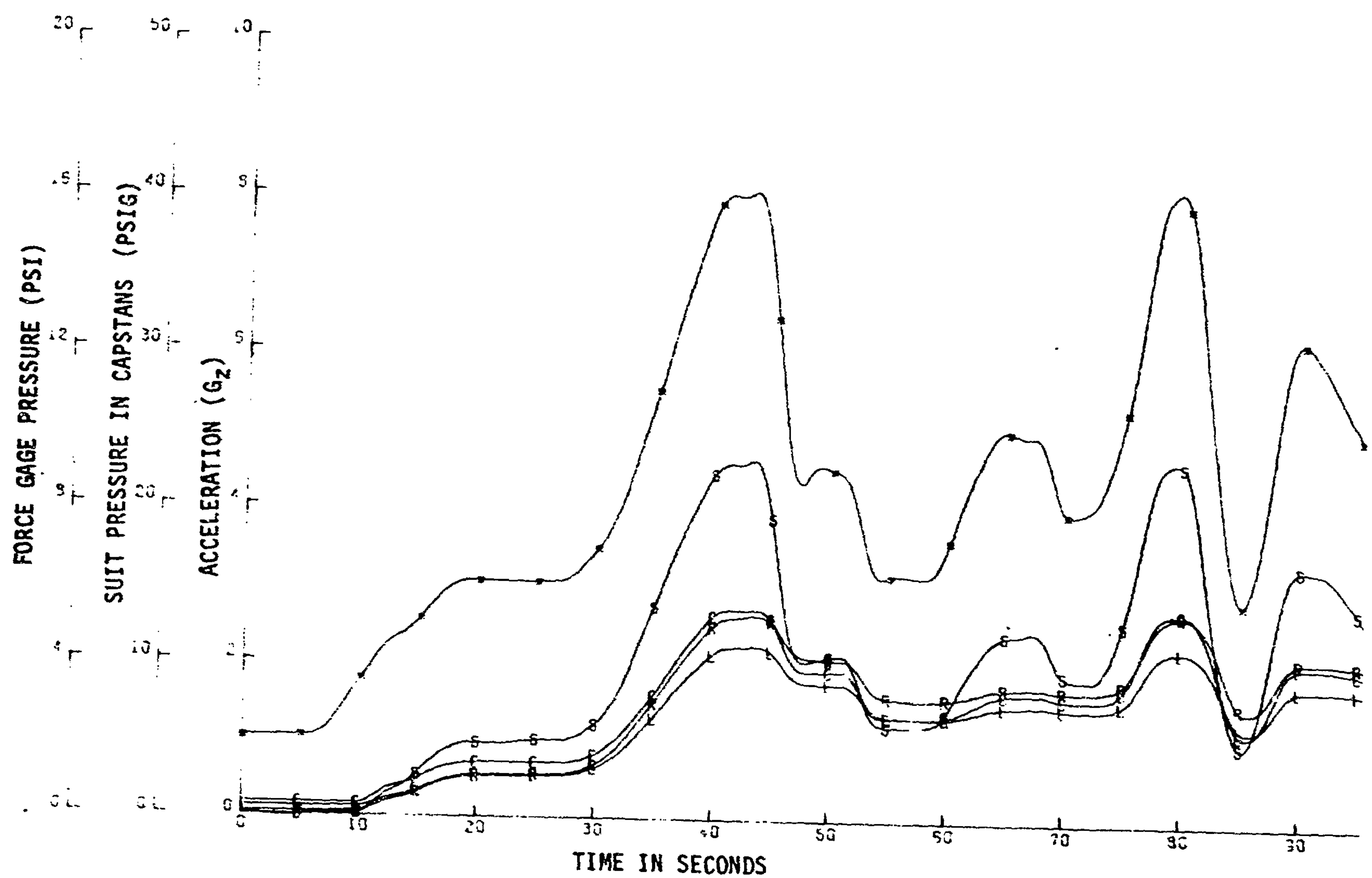

Figure 50. The G_z, capstan pressure, and force gage pressure (left calf, left thigh, and right thigh) vs. time, for a simulated aerial combat maneuver. [Curves are: *, S, C, R, and L. For "Key," refer to Table 48.]

7. CONCLUSION

As the concluding volume in this series under the TEHG program, Volume III has incorporated detailed information on the anti-G suit portion of the research. Hence the respective sections in this volume are condensations of exhaustive tests on: the operation, monitoring, and test protocol of the anti-G suits; the various types of suits; the field-test procedures for the anti-G protective systems; and the supplemental evaluation of the Pneumatic Lever (Capstan) suit.

Related material is available in: Volume I (SAM-TR-78-10), which includes descriptions of the elements of data measurement and handling common to the majority of the tests, as well as comprehensive information on the miscellaneous tests and their results; and Volume II (SAM-TR-78-11), which contains reports on the anti-G valve tests and on the Standard Anti-G Valve Test Protocol.

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ACM	Aerial Combat Maneuver(s)
AN	Army-Navy (used in the identifying numbers of parts or fittings)
ASG	Aeronautical Standards Group
F_v	air flow
G_z	acceleration along the Z axis (head to foot)
Hg	mercury
i.d.	inside diameter
$in.^3$	cubic inch(es)
kg	kilogram(s)
lbf	pound-force
LBFP	Lower Body Full Pressure (anti-G suit)
max	maximum
mid	median
min	minimum
NOMEX	trade name of a high-temperature resistant cloth
P00006	extension to the basic TEHG contract with USAFSAM
P_b	anti-G suit bladder pressure
P/N	part number
P_s	source pressure
psi	pounds per square inch
psia	pounds per square inch absolute
psid	pounds per square inch differential
psig	pounds per square inch gage
P_v	suit pressure
SACM	Simulated Aerial Combat Maneuver(s)
SAM	School of Aerospace Medicine (Brooks AFB, Tex.)
SAV	standard air volumes
SCF	standard cubic foot
SCFM	standard cubic feet per minute
VNB	Biodynamics Branch, of the Crew Technology Division (SAM/VNB)
V_s	suit volume
XDCR	transducer

LIST OF APPENDIXES FOR THE TEHG SERIES: VOLUMES I, II, and III

(Although the information in these Appendixes pertains to all three volumes, most of the data in A - B apply especially to Vol. I; in C - G.2, to Vol. II; and, in H - M.2, to Vol. III.)

A. Mass spectrometer data curves

B. Pressure transducers data curves

C. Hymatic VAG 110-007 anti-G valve data curves

D. ALAR 88535-8400A anti-G valve data curves

E. Bendix FR-139-A2 anti-G valve data curves

F. USAFSAM electronic anti-G valve data curves

G.1. The 10-G mode Honeywell fluidic anti-G valve data curves

G.2. The 50-G mode Honeywell fluidic anti-G valve data curves

H. CSU 12/P anti-G suit data curves

I. CSU 13/P anti-G suit data curves

J. CSU 15/P anti-G suit data curves

K. RAF mini anti-G suit data curves

L. Lower body full pressure anti-G suit data curves

M.1. Bladder USAF pneumatic lever anti-G suit data curves

M.2. Legs USAF pneumatic lever anti-G suit data curves

N. Mass spectrometer data analysis program listing

O. Pressure transducer data analysis program listing

P. Anti-G valve data analysis program listing

Q. Anti-G suit data analysis program listing

R. Supplemental pneumatic lever evaluation program listing

[How to order Appendixes A - R]

RE: The USAF School of Aerospace Medicine's Technical Report Series on Engineering Test and Evaluation During High G--Volume I (SAM-TR-78-10), Volume II (SAM-TR-78-11), and Volume III (SAM-TR-78-12)

APPENDIXES A - R:

In order for comprehensive information on this research to be readily accessible, microfiche have been made of these Appendixes. The microfiche are available, individually or collectively, through:

The Strughold Aeromedical Library
Documentation Section (SAM/TSK)
USAF School of Aerospace Medicine
Brooks AFB, Texas 78235